ORBITAL SPACE DEBRIS

HEARING

BEFORE THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDREDTH CONGRESS

SECOND SESSION

JULY 13, 1988

[No. 112]

Printed for the use of the
Committee on Science, Space, and Technology

U.S. GOVERNMENT PRINTING OFFICE

88-188 ⇆ WASHINGTON : 1988

For sale by the Superintendent of Documents, Congressional Sales Office
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*Ranking Republican Member.

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ORBITAL SPACE DEBRIS

WEDNESDAY, JULY 13, 1988.

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, D.C.

The subcommittee met, pursuant to call, at 10:20 a.m., in room 2325, Rayburn House Office Building, Hon. Bill Nelson [chairman of the subcommittee] presiding.

Mr. NELSON. We apologize for the late start. There was a Democratic Caucus this morning in which the soon-to-be two nominees were speaking, so all of our Members on this side of the aisle were engaged.

We are delighted to be here on a topic that has been of considerable concern to this committee. We had announced last year that we were going to be moving to have a hearing on this problem, this increasing problem, of space debris. Now it is no secret; I mean it is a problem. A tiny paint chip caused a considerable chip in the window of a previous space shuttle flight. There are no rhymes or reason to the specific orbits of this debris, and at orbital speed which is in excess of 17,000 miles an hour, with orbits criss-crossing each other, particularly at the altitude in which a lot of our low-Earth orbit activity occurs, you can start to see the magnitude of the problem for not only us but any space-faring nation.

So we are starting our oversight hearings in this subcommittee on this problem. It obviously is not only important to the area of space activity of jurisdiction of this committee, the civil space program, but obviously it has enormous national security implications, as well as to our commercial space effort.

Now in the future, our space assets are going to be larger, they are going to be of lighter construction, they are going to be longer lived, and so the problem of orbital debris is going to be all the more important. What we want to do today is start to energize ourselves to figuring out what we ought to do about this problem before we have a catastrophe. We must find a way to preserve the pristine environment of space if we are going to continue to use that low-Earth orbit and expand there our human presence in space. Now it is also important that we preserve that environment just for its own sake. We must continue to explore without destroying. We must exploit without squandering.

I had the privilege of looking back and seeing the entire ecosystem at once, and that was a rather extraordinary perspective for someone as an environmentalist. It is clear that if we ignore this problem, if we do not act to eliminate man-made space debris, then

future generations are not going to have the advantage of our activities in space that are designed all the more to preserve our environment, Sally Ride's suggestion in her report of Mission to Planet Earth, which is a follow-on to Landsat and a host of other activities.

Aside from looking back terrestrially as we look out into the heavens, what could happen to the Hubble Space Telescope, what could happen to the Space Station, both the United States and the Soviet, and so our purpose today is to assess the debris hazard and to hear proposals to limit the accumulation of debris fragments in our now frequently used low-Earth orbit.

Now we are pleased in this committee that we have seen some concern about orbital debris in a recent presidential space policy statement. We would like to commend the Department of Defense for being the first to formulate a policy to control the proliferation of debris fragments, and we hope that this hearing today will help increase our awareness of this potential danger to space missions. Only with this awareness and by our leadership can we hope to approach the other space-faring nations and ask them to join us in addressing this problem.

So we are going to welcome Joe Mahon, Deputy Associate Administrator for flight systems in NASA; Phil Kunsberg, Assistant Deputy Undersecretary of Defense for Policy; Mike Michaud, director, Office of Advanced Technology in the Department of State; Courtney Stadd, who is the director of the Office of Commercial Space Transportation in DOT; Neil Hosenball; Neil is former general counsel to NASA; and Nicholas Johnson, Teledyne Brown Engineering Corp., and he has a book out on artificial space debris.

I will insert in the record a statement from our ranking Member, and we will proceed, the first panel from Mahon to Stadd. So let's start with you, Mr. Mahon.

STATEMENTS OF JOSEPH MAHON, DEPUTY ASSOCIATE ADMINISTRATOR FOR FLIGHT SYSTEMS, OFFICE OF SPACE FLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D.C., ACCOMPANIED BY DON KESSLER, JOHNSON SPACE CENTER; PHILIP KUNSBERG, ASSISTANT DEPUTY UNDERSECRETARY OF DEFENSE FOR POLICY, U.S. DEPARTMENT OF DEFENSE, THE PENTAGON, WASHINGTON, D.C.; MICHAEL MICHAUD, DIRECTOR, OFFICE OF ADVANCED TECHNOLOGY, U.S. DEPARTMENT OF STATE, WASHINGTON, D.C.; AND COURTNEY STADD, DIRECTOR, OFFICE OF COMMERCIAL SPACE TRANSPORTATION, U.S. DEPARTMENT OF TRANSPORTATION, WASHINGTON, D.C.

Mr. MAHON. Thank you, Mr. Chairman.

In view that you have given my presentation quite aptly during your introduction and, with your permission, I would like to submit a written statement for the record and then summarize briefly what has been going on in our space program.

Mr. NELSON. Please. Thank you.

Mr. MAHON. First, I would like to call your attention that we do have on display on this table here some of the problems, or the impacts that the space hits have done, actual from space and from

laboratory tests, and it's pretty graphic that the problem is there in some degree today, and we would like to discuss that on that basis.

The success depends on a space environment sufficiently free from debris to enable safe, dependable operations of manned and unmanned flights. An environment that is overly cluttered with debris threatens our ability to utilize space to provide a scientific variety of technical and commercial purposes. The situation is not serious now, but the trend is a real concern. We see it growing now, and we have recognized this problem and acted on the need to take steps now to better understand that problem and to develop the means to manage the situation before it becomes a real threat in the future.

Mr. Chairman, you referred to the national space policy and the steps that have been taken there. I would like you to be advised that we are providing a working group for the space debris that has been established. It is cochaired by NASA and the DOD. It includes members of all the Interagency Group agencies—DOT, State, Commerce—who are interested in space debris. We did hold meetings last week. We had the first meeting to implement the terms of reference for an interagency study to provide a report defining the dimensions of the current and projected space debris problems. We view existing agency debris problems and activities, make recommendations on a broad policy, and submit a report in 180 days to the Interagency Group-Space for review.

Together, the National Space Policy and its Working Group activity and our own ongoing efforts internal to NASA and DOD reflect a commitment to better understand the orbital debris environment and to develop—your concern—appropriate countermeasures. I'd like to go into a little bit of what we know and what we're trying to learn on that one now.

Over 7,000 man-made objects big enough to be tracked are being tracked; in addition, other man-made material too small to be easily detected. Collectively, this debris known as orbital debris, it consists of spent spacecraft rockets, spent upper stages, separation devices, fragments of exploded systems that have been in space and are orbiting and are raining down. Most reside at an altitude of prime interest, below 1,600 kilometers, or about 900 miles in space.

As the Earth travels around the Sun, natural objects can and do impact the Earth and spacecraft. Compared to these natural objects, the debris—man-made debris is about four times the order of magnitude of the natural objects in there, and so a spacecraft is more likely to be hit by man-made debris than by natural debris.

Debris objects are a double concern. The first concern is the individual threat that they give themselves to an object if they were to impact it. The second concern is that when they impact another object, many more fragments are created. The collision energy is higher. As you said, it was 17,000 miles per second. That is about 15 kilometers per second or 9 miles a second when they impact on that one, and they generate a large number of small fragments, many of which are too small to be observed or tracked but are big enough to threaten a system. Any level of hazard to a system—to a given spacecraft depends on the size and the protective features of that spacecraft, the number and size of the debris fragments that

are in the operating environment, and the length of time the spacecraft is in orbit.

Let me emphasize then that what we are seeing now—and I will give you an example of that—the average time between collisions that might be damaging to an orbiter at 300 kilometers is the average time today, 1988, with 71 years on orbit based on the projected 1988 density. In the year 2000, the average time between collisions has gone down to 26 years; and in 2010 the average time between collisions that could occur will be down to 8 years; and this assumes that no further steps are done to reduce the trend in debris growth. A long lead time to design and develop the spacecraft is necessary, so that it's necessary, as you inferred, sir, that we take this initiative, corrective action, now.

To our knowledge, no spacecraft has been disabled or destroyed by orbital debris. You did mention the space shuttle orbiter window which was hit by a paint chip. Projected growth, especially for large spacecraft over a long period of time, says that we would have trouble with these spacecraft. We need to understand the current environment and study how to manage these hazards.

Where do we get our knowledge from? The U.S. Space Command and their radar provide many—much tracking information, but their radar at this point cannot detect objects smaller than 8 to 10 centimeters at 500 kilometers. The models I used to extrapolate the particle distribution of small debris, which is on the order of 1 to 10 centimeters, that analysis said that this distribution is extensive. It ranges from 20,000 to 60,000 fragments in space.

Considerable uncertainty resides in that area, and we tried to define that. Johnson has a contract with MIT for the use of the radar, an optical radar, at the Lincoln Laboratory, and using this Lincoln Laboratory 31-inch telescope we found a larger number of smaller particles given the size of the catalogued population, those which we can actually see. Three to five times the number of catalogued population were observed under average to good viewing conditions.

Our knowledge is also supplemented by some tangible evidence. We have one, the shuttle flight, and we have the thermal protection system showing evidence of high-speed collision with tiny shards of man-made material. One-tenth of a millimeter is about the size of a period on a page, and that is significant to do damage to the thermal protection system. It was the size of about two-tenths of a millimeter that hit the window that you were discussing during that period of time.

Objects of greatest concerns to orbiting spacecraft would be those in the size of the range of 1 millimeter to 10 centimeters. Now what we are talking about here is the diameter of a pen to the diameter of a baseball. They are too small to be seen by radar during that period of time, and yet we want to be able to catalogue those and be able to predict how extreme that is.

So we do have a radar on orbit. We are building a radar to determine these pieces in orbit. We want to have that radar be able to—a special radar to the 1- to 10-centimeter critical range. The requirements for that radar have been defined. We are ready to release the RFP's at the end of this year. The driver for that information is the space station critical design review scheduled for

1991. The radar will provide data for the design of the space station shielding.

Given the size of the station and its relatively permanent nature, shielding is an important design. Today, the station's current design of using multi-layer insulation, stand-off bumper shielding in both areas, are sufficient for the protection that is necessary. If we find out that the debris is greater in that regard, we can then go to a growth concept and install a double shield while it's on orbit. So that we are sure that we have the space station covered now with the debris, but we want to measure that debris to ensure that we're in that capability.

We have a three-step program going in NASA to cover the growth of orbital debris. The first one is technical in nature. We are trying to characterize the space debris, develop suitable math models to maintain the data base, test the debris impacts, as well as do research on materials and structure which are best oriented to prevent the collisions from happening. It involves development of shielding and other protection measures.

The second part of it is the measurement-oriented step, and that is where the radar comes in. We are developing that special radar to be able to cover debris which is not visible in today's environment, and then a policy-oriented step which is to devise management options for orbital debris prevention, protection, and possible elimination.

Policy guidance—agency-wide OD Steering Group, Orbital Debris Technical Coordinating Committees, have been established at JSC. We need more, but we have taken some concrete steps. For example, on the Delta stage, we found out that they were exploding after many years in orbit due to the propellants deteriorating and there being a hyperdrolic situation exploding, causing more debris on that one. We have taken steps that all those stages of that type are vented of their propellant so that they do not contribute to the orbital debris, and since that policy has been initiated we have not had more of that type of situation.

We studied, and with the DOD worked on, an experiment to perform—NASA and DOD are working on the Delta 180 launch. We have the experiment conducted at an altitude where 90 percent of the debris had fallen down and could not remain in orbit at the end of three to six months. So we have things working. We are working with ESA in providing the Delta experience to Arianespace so that they can learn the process and prevent explosions from the Ariane second and third stages from occurring, because there is history of having one of those occur in that regard.

We are working with Germany on creating information on tracking tomorrow's debris problems. We are considering ways to involve other space-faring nations, but the problem is that it is international in scope. We are not the only contributors. We need help in this regard.

In summary, sir, I would like to say we recognize the importance of this thing and think we are taking concrete steps to put a handle on it to determine where we are going, and why we are doing it, and what we can do to prevent it.

[The prepared statement of Mr. Mahon follows:]

NASA
National Aeronautics and Space Administration

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Presented by Witness

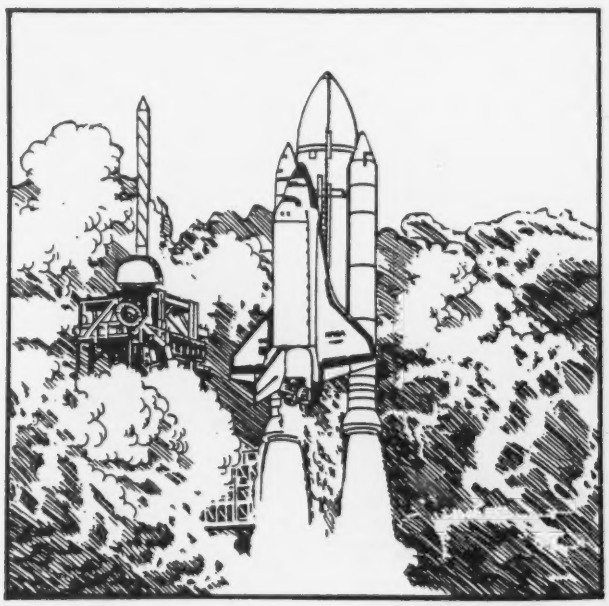
July 13, 1988

Subcommittee on Space Science and Applications
Committee on Science, Space, and Technology

House of Representatives

Statement by:

Joseph B. Mahon
Deputy Associate Administrator for Space Flight (Flight Systems)



100th Congress

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Statement of

Joseph B. Mahon
Deputy Associate Administrator (Flight Systems)
Office of Space Flight

National Aeronautics and Space Administration

before the

Subcommittee on Space Science and Applications
Committee on Science, Space, and Technology
House of Representatives

Mr. Chairman and Members of the Subcommittee:

I appreciate the opportunity this morning to appear before you to discuss the subject of orbital debris.

NASA's interest in minimizing orbital debris is fundamental. The success of our endeavors in space depends upon a space environment sufficiently free of debris to enable the safe and dependable operation of manned and unmanned spacecraft. An environment overly cluttered with debris would threaten our ability to utilize space for a wide variety of scientific, technological, and commercial purposes. While the situation is not yet serious, the trend is of real concern. We have recognized and acted upon the need to take steps now to better understand the problem and to develop means to manage the situation before it becomes a potential threat to our future in space, and to that of other spacefaring nations.

In recognition of this potential problem, the Administration's National Space Policy states that:

> "...all space sectors will seek to minimize the creation of space debris. Design and operation of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness."

Additionally, the National Space Policy also mandated the formation of an ad hoc interagency working group to provide recommendations on the implementation of the space debris policy. This group, the IG(Space) Working Group for Space Debris, has been established and is co-chaired by NASA and the Department of Defense and includes members from all of the IG(Space) agencies. The IG(Space) is a sub-group of the

National Security Council's Senior Interagency Group(Space).

The working group had its first organizational meeting last week, and established the plan and schedule to implement the Terms of Reference for this interagency study.

The Working Group has been directed to define the dimensions of the current and projected space debris problem, review existing agency debris policies and activities, review options for reducing the production of space debris and minimizing hazards to spacecraft from it, recommend approaches to other governments, recommend areas for potential future research both with regard to debris environment measurement and modeling and with regard to protection techniques, and, finally, prepare additional broad policy recommendations. The IG(Space) Working Group will submit its report within 180 days to the IG(Space) for review.

Together, the National Space Policy and the Working Group activity, combined with on-going efforts within NASA and the Department of Defense, reflect a commitment to better understand the orbital debris environment and to develop appropriate additional counter-measures.

Let me describe what we know today about orbital debris, and what we still need to learn. Approximately 7,000 man-made objects large enough for routine tracking by radar and optical sensors are now in orbit. In addition to these known objects, there is a significant quantity of other man-made material too small to be easily detected. Collectively, the portion of the known objects that are not actually functional spacecraft and the body of associated smaller materials are referred to as "orbital debris." This man-made debris consists of spent spacecraft, rocket stages, separation devices and fragments of exploded systems. Much of the debris is resident at altitudes of prime operational interest, specifically, below 1600 kilometers.

There are also, of course, natural objects that can and do impact spacecraft. These meteoroid materials cross low-Earth orbits as the Earth passes through space around the Sun. If the total masses are compared, the known debris environment is almost four orders-of-magnitude greater than that of the natural meteoroid environment. The orbital debris, like the meteoroid environment, forms a relatively constant shroud around the Earth. For the most part, spacecraft are now more likely to be impacted by orbital debris than by small micrometeorites.

Each debris object is of concern both as a collision threat and as a source of more fragments upon collision with other objects. Collision energy is high—relative velocities may reach values of 15 km/sec., averaging about 10 km/sec., at those points where the orbits intersect—and can generate large numbers of fragments too small to observe or track readily, but still large enough to threaten an operating system. The level of hazard to a given spacecraft depends on the size and protective features of the spacecraft, the number and size of debris fragments in its operating environment, and the length of time the spacecraft remains in orbit.

I must emphasize, however, that at this time the hazard to spacecraft is more a projected rather than a present danger. The average time between collisions that might be damaging to an orbiter at 300 km is 71 years on-orbit based on the 1988 debris density, 26 years for the debris density projected for the year 2000, and 8 years for the projected 2010 debris density. This assumes that no further steps are taken to reduce the historical orbital debris growth trend. In view of the long-lead time required to design and develop spacecraft and space-based facilities, it is necessary to initiate corrective measures in the near term.

To our knowledge, no spacecraft has yet been disabled or destroyed by orbital debris. However, spacecraft have been struck by debris; for example, a chip of paint, traveling at two-to-four miles-per-second dug a small but noticeable pit in a window of an orbiter during one of the Space Shuttle flights. The remote possibility exists that a spacecraft currently in orbit could be put out of commission. Given the current extent of space debris, and the projected growth of both debris and spacecraft, orbital debris is likely to pose an increasing risk to spacecraft. Especially vulnerable may be large spacecraft operating over long periods of time. Efforts must be continued toward understanding the current environment and studying possible methods of managing the hazards presented by orbital debris.

Much of our knowledge about orbital debris comes from data obtained from the satellite tracking network, operated by the U.S. Space Command. However, the command's radar cannot detect debris smaller than about 10 cm in diameter at 500 km. Hence, models are used to extrapolate the particle distribution of small debris ranging in size from 1 to 10 cm. Some analysis suggests the distribution in this range is extensive: 20,000 to 60,000 small fragments. The probability that so many objects are in orbit underscores the potential significance of the orbital debris threat.

Considerable uncertainty exists as to the current and projected population density of this small size debris, however, and efforts have been made to measure objects smaller than those detectable by Space Command. One such effort was conducted by the Massachusettes Institute of Technology's Lincoln Laboratory, under contract to NASA's Johnson Space Center. Using the Lab's 31-inch telescope in a series of observations, the MIT team found a larger number of smaller particles than had been expected, given the size of the catalogued population. In one instance, under viewing conditions considered only average, the team found three times the number of catalogued objects. Under conditions considered excellent, the MIT group detected five times the catalogued number.

Our knowledge of orbital debris is supplemented by some tangible evidence. Here, we are dealing with objects 0.1 mm and smaller (one-tenth the diameter of a period). After one of the Space Shuttle flights, the orbiter thermal protection system showed evidence of a high-speed cc sion w'th a tiny shard of man-made debris. The Solar Max Repair Mission also provided additional data. Over 3,000 hits were recorded in 1.5 square meters of thermal blanket, and one square meter of aluminum louvers, a sizeable fraction of which are believed due to man-made debris. Scanning by electron microscopy has shown that many of these hits were due to tens-of-micron-sized paint chips, whose origin is uncertain but which may have resulted from the degradation of painted satellite surfaces due to atomic oxygen erosion, thermal cycling stresses, or radiation from the Sun.

The objects of greatest concern to orbiting spacecraft in low-Earth orbit would be those in the size range of 1 to 10 cm (the diameter of a pen to that of a baseball). Such objects have enough size and mass, and exist in sufficient number to yield significant damage probabilities if present debris trends continue for long. Smaller objects, such as those that hit Solar Max, although more numerous, do not possess sufficient mass to inflict significant damage in the event of a collision, and larger objects are not sufficiently numerous to yield significant impact probabilities. Yet, data on objects in the critical 1 to 10 cm size range is lacking.

One spacecraft already in orbit can be expected to improve our knowledge of orbital debris. This is the LDEF, the Long Duration Exposure Facility. Launched by the Space Shuttle in 1984, LDEF is covered with test plates for various experiments, each of

which no doubt have been struck repeatedly with meteroids and man-made objects. Presently, LDEF is scheduled to be retrieved in July of next year. Its yield of relevant orbital-debris data should be rich indeed.

So far, I've been discussing orbital debris at low-Earth orbit. At higher altitudes, the problem, while less severe, is still present. As orbital altitude increases, useable volume expands geometrically and the relative inertial velocities decline, mitigating the consequences of collision. Thus, orbital debris at geosynchronous altitudes is not currently a serious problem. Nonetheless, because of the great value of geosynchronous orbit and the projected increase in the use of this orbit over the next 10 to 20 years, studies of orbital debris in this region of space are being initiated.

Over ten years ago, NASA recognized that a potentially hazardous situation could develop as orbital debris accumulated and the number of orbiting spacecraft increased, and began to study the orbital debris environment. Since then we have worked to characterize the nature and population density of space debris, to assess the impact of collisions between debris and spacecraft, to develop protection techniques, and to work with other agencies to construct a feasible policy.

In July, 1987, the NASA Administrator directed the Office of Space Flight to devise an orbital debris strategy for the agency. After extensive consultations within NASA, the Office has devised an approach that has three key thrusts. Dr. Fletcher has reviewed the strategy and directed that it be implemented.

The first thrust is technical in nature. It consists of further characterizing the space debris environment which necessitates developing suitable mathematical models and maintaining a data-base. Testing of debris impacts as well as research on materials and structures is also part of the effort. As you would expect, this thrust involves the development of shielding and other protection techniques.

The second thrust is measurements-oriented, rather than analytical in character. It is the development of a special radar, capable of detecting debris in the critical 1 to 10 cm range, where our data-base is incomplete. An Orbital Debris Radar Development Program has been establishc Requirements are being defined and an overall architecture conceived. The current plan is for NASA to have the Request For Proposals (RFPs) ready for release by the end of this year. Driving the schedule for this radar, along with the requirement to fill the gap in our knowledge as soon as possible, is the Space Station Critical Design Review, scheduled to begin in the middle of 1991. The radar will provide important additional data for the design of the Station's orbital debris shielding.

Given the permanent nature of the Space Station, and its relatively large size, adequate shielding becomes an important design parameter. A firm requirement to protect the Station against a future orbital debris hazard has been documented and the baseline design addresses this requirmement. However, the new radar is needed to obtain debris density data to verify the requirement. If more shielding is being planned than in fact is needed, an unnecessary weight penalty would be paid. If the currently planned level of shielding turns out to be inadequate, then a risk would be incurred that would have to be reduced. Current design concepts to protect the pressurized elements of the Space Station involve the use of doubled-walled structures and multi-layer insulation on the pressurized elements to augment the intrinsic protection due to the wall thickness of the pressurized element. In addition to this insulation, a bumper shield will be deployed at the forward edge of the pressurized elements to provide additional debris protection. Tests have proven that a bumper shield coupled with multi-layered insulation

efficient protection against hypervelocity particles. The Space Station is being designed so that additional bumper shields could be added on orbit. In addition, materials are being tested that might lead to a more effective bumper shield.

The third thrust of NASA's orbital-debris strategy is policy oriented. It consists of devising management options for orbital debris prevention, protection, and possible elimination. Policy guidelines will be the result of this activity, which is addressed by an agency-wide Orbital Debris Steering Group. This group reviews orbital debris planning and makes technical and policy recommendations to the Office of Space Flight. The group is assisted by a Orbital Debris Technical Coordination Committee at the Johnson Space Center. This committee is responsible for the design and execution of our orbital debris technical analyses. This effort takes advantage of the expertise resident in the various flight programs throughout NASA.

I would like to emphasize that much of what we must do now is largely analytical in character. We need to know more than we do about orbital debris. For example, we need to generate improved computer models for hypervelocity impacts. We need to develop detection and avoidance concepts. And we need to consider whether small flight experiments of debris protection concepts should be devised. Of course, the internal NASA effort concerning orbital debris will be coordinated with the IG Working Group activity.

While we clearly need to know more about orbital debris, NASA has already taken some concrete steps to reduce the amount of debris in space. Perhaps the most significant has been the NASA requirement in force since 1982 which established the procedure for Delta upper stages of venting the unspent propellants and gases to prevent the explosion of the Delta upper stage due to the mixing of fuel residues. No U.S. cryogenic stages have inadvertently exploded in space. In another step taken by the United States to reduce the hazard of orbital debris, NASA provided technical guidance to a recent Department of Defense space project to minimize the time debris resulting from the experiment was in orbit. By operating at a prescribed altitude, over 90% of the debris reentered the atmosphere within six months.

I also would like to emphasize that any approach reducing the risk to spacecraft from orbital debris must be international in character. Man-made debris comes from the spacecraft of many nations and threatens the space activities of all spacefaring nations. The United States should not be acting alone in this regard. Only a cooperative effort in approaching the problem of space debris can be successful. Some international activity is already underway. The European Space Agency (ESA) is concerned about orbital debris, and a NASA-ESA Working Group on Space Debris has been meeting to share technical data on the debris population and to work together to reduce the accumulation of orbital debris by applying our Delta experience in their Ariane operations. In addition, NASA is negotiating an agreement with the German space authorities to exchange data on debris measurements. Also, NASA is assisting the Department of State by providing technical advice on a study of orbital debris by the International Telecommunications Union. Finally, we are considering ways of involving other spacefaring nations in data exchanges and other efforts to control the growth of orbital debris.

In summary, Mr. Chairman, NASA recognizes the operational significance of orbital debris. We have under way a set of activities designed to improve our knowledge of the debris environment and to determine suitable countermeasures. A special radar is to be developed to fill the most important gap in our knowledge. Some steps already have been taken to reduce the amount of debris in orbit. Most importantly, the Administration has established an ad hoc working group on orbital debris to provide within 180 days

recommendations on how best to implement the National Space Policy directive on orbital debris. In concert with other spacefaring nations, the United States should continue its efforts to deal with debris in space, but it should do so with deliberation and with a more complete understanding of the subject.

That concludes my prepared statement. My colleagues and I are ready at this time to answer any questions that you may have.

Mr. NELSON. Thank you, Mr. Mahon.

As we proceed on the panel—and we want a summary of your remarks, and we will enter your prepared testimony into the record—consider, as we go on—and we will get into the questions after each of you have made your informal statements—that, in fact, I thought we had evidence that we have seen destruction of spacecraft in orbit, contrary to what you said, Mr. Mahon—for example, a couple of Kosmos, GEOS, PAGOS.

Talk to us about the shielding that might be necessary on the space station. Talk to us about ASAT's, the considerable testing program of the Soviets and the debris that is there as a result of our ASAT test, and what is the potential in the future there.

So let's hit all of these subjects, and also give us some idea of, in low-Earth orbit, the amount of debris that is there that will degrade and come back into the atmosphere as a percentage, say, using what is there now, what percent of that is going to degrade and come back that we don't have to worry about and what is still out there. And then look at things like, tell us about how we paint our rockets and where did that paint chip come from, and now that the Soviets are painting their rockets with logos, do we have to worry about those paint chips, and if a piece of paint almost the size of a period is what caused the chip in the space shuttle window, then should we not be painting rockets?

Okay, Mr. Kunsberg, your summary, please.

Mr. KUNSBERG. Thank you, Mr. Chairman. It's clear that you and the other members of the committee are quite learned about this subject, so I will just briefly summarize my testimony.

The first point I would like to make is that we have been thinking about this problem for some time. We have been very conscious of it in DOD, and, in fact, the DOD space policy that was promulgated in February of 1987, for the first time, at least within our own policy statements, took a clear position on space debris, and, as you know, it provides that DOD will take affirmative action to minimize the creation of space debris in its activities. That is a very important concept for us and one that we're trying to take very seriously by taking account of space debris problems in our planning stage of space activities and in the building and design of space systems.

The Delta 180 experiment which Mr. Mahon referred to, I think, was a very important example of this. In fact, what we did is, we deliberately conducted that experiment which, as you know, involved the collision of two vehicles at the termination phase, in as low an orbit as possible, with the result that after 180 days nearly all of the debris created by that collision re-entered the atmosphere and burned up and so was no longer a problem.

We feel that by actions of that nature we can deal effectively with the problem of space debris without adversely affecting our paramount national security missions, and so we do not see these as being inconsistent in any way.

Finally, as you know, and as Mr. Mahon has mentioned, we have embarked upon an interagency process to very exhaustively consider our policy on space debris, and we see this as an opportunity to put our experts together to thoroughly analyze the problem and the state of our policies and regulations as they are and, further, to

examine what needs to be done in this area and to make specific recommendations along those lines, and we have very precise terms of reference for that study and some very relatively near-term deadlines. We expect to produce that study, as called for by the National Space Policy, by December 15 of this year. So we are on course, and we are working intensively on it, and we think that we can make a useful contribution.

The final point I would make is that this is, of course, an international problem. The Soviet Union, for example, has the greatest launch rate of any other nation and therefore most recently has made the larger contribution to the space debris problem as a result of that launch rate.

In addition, we are witnessing tne emergence of other nations that are going to commence or have commenced regular launch activities, and this will undoubtedly increase the problem, and it clearly in the long term requires some sort of international solution, but in the meantime there are actions that we can take as a nation to set an example and to make sure that we have a sound policy basis on which to enter the international discussions that ensue.

So that, in summary, is my statement, and I would be pleased to answer any questions.

[The prepared statement of Mr. Kunsberg follows:]

STATEMENT BY PHILIP KUNSBERG

BEFORE THE

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

JULY 13, 1988

SPACE DEBRIS

MR. CHAIRMAN, MEMBERS OF THIS COMMITTEE, THANK YOU FOR THE OPPORTUNITY TO PRESENT THE PERSPECTIVE OF THE DEPARTMENT OF DEFENSE ON THE PROBLEM OF SPACE DEBRIS. MY NAME IS PHILIP KUNSBERG. I AM ASSISTANT DEPUTY UNDER SECRETARY FOR POLICY. I HAVE RESPONSIBILITY FOR SPACE POLICY WITHIN THE OFFICE OF THE SECRETARY OF DEFENSE.

FOR SOME TIME, IN DOD, WE HAVE BEEN VERY CONSCIOUS OF THE POTENTIAL DANGER TO SPACE VEHICLES PARTICULARLY IN LOW EARTH ORBIT, CAUSED BY THE ACCUMULATION OF ORBITING, MAN-MADE OBJECTS, AND FRAGMENTS OF OBJECTS THAT HAVE EXPLODED OR COLLIDED. WE ARE ALSO CONSCIOUS OF THE POTENTIAL DANGER TO PEOPLE AND PROPERTY PRESENTED BY A LARGE OBJECT DECAYING FROM ORBIT. WITHIN THE FEDERAL GOVERNMENT, DOD HAS BEEN A LEADER IN TAKING POSITIVE ACTION TO FULLY UNDERSTAND AND ALLEVIATE THIS PROBLEM. THE AIR FORCE FOR EXAMPLE REVIEWED THE

ISSUE AS EARLY AS 1983 AND AGAIN IN 1987. RESULTS OF THESE EFFORTS LEAVE US WELL POSITIONED TO ADDRESS THE PROBLEMS IN AN INTERAGENCY FORUM -- AND WE ARE DOING SO.

THE DOD SPACE POLICY, ISSUED IN FEBRUARY 1987, BROKE NEW GROUND BY EXPRESSLY ADDRESSING SPACE DEBRIS AS A FACTOR IN PLANNING OF MILITARY SPACE OPERATIONS. THIS GUIDANCE WAS ALSO INCLUDED IN THE RECENT NATIONAL SPACE POLICY FOR ALL SPACE SECTORS. BOTH POLICIES CALL FOR AFFIRMATIVE EFFORTS TO MINIMIZE THE CREATION OF SPACE DEBRIS. THE DOD SPACE POLICY STATES:

> DOD WILL SEEK TO MINIMIZE THE IMPACT OF SPACE DEBRIS ON ITS MILITARY OPERATIONS. DESIGN AND OPERATIONS OF DOD SPACE TESTS, EXPERIMENTS AND SYSTEMS WILL STRIVE TO MINIMIZE OR REDUCE ACCUMULATION OF SPACE DEBRIS CONSISTENT WITH MISSION REQUIREMENTS.

OF COURSE, THIS DOES NOT MEAN THAT WE WILL CURTAIL OR AVOID SPACE ACTIVITIES THAT ARE NECESSARY FOR OUR NATIONAL SECURITY. THIS REQUIRES US TO TAKE FULL ACCOUNT OF THE HARMFUL EFFECTS OF SPACE DEBRIS EARLY IN OUR PLANNING AND, WHEREVER POSSIBLE, TO MINIMIZE THOSE EFFECTS WITHOUT COMPROMISING OUR PARAMOUNT NATIONAL SECURITY MISSION.

I EXPECT THE COMMITTEE IS MOST INTERESTED IN HOW DOD INTENDS TO CARRY OUT THIS POLICY. THE FIRST PREREQUISITE TO EFFECTIVE ACTION IS A DATA BASE ON THE CURRENT SITUATION. OUR SPACE SURVEILLANCE NETWORK PROVIDES A THOROUGH AND ACCURATE CATALOG OF THE POPULATION OF ORBITING OBJECTS THAT ARE IN EXCESS OF 10 TO 20 CENTIMETERS IN DIAMETER. THE NERVE CENTER OF THIS NETWORK IS MAINTAINED BY THE U S. SPACE COMMAND AT COLORADO SPRINGS, WITH A BACKUP FACILITY AT NAVY SPACE COMMAND AT DAHLGREN, VIRGINIA. DATA FROM RADAR AND OPTICAL SENSORS AROUND THE WORLD ARE INTEGRATED, ANALYZED, AND CONTINUOUSLY UPDATED AT THESE CENTERS. THIS CAPABILITY TO ACCURATELY CATALOG AND TRACK RELATIVELY LARGE OBJECTS IN NEAR-REAL TIME IS ESSENTIAL TO THE SAFETY OF OUR CIVIL AND MILITARY SPACECRAFT, AND A FIRST ORDER REQUIREMENT IN DEALING WITH SPACE DEBRIS. THE SPACE OBJECT CATALOG CURRENTLY IDENTIFIES MORE THAN 6000 OBJECTS AT ALTITUDES BELOW 2000 KILOMETERS.

IN ADDITION, THE DOD PERIMETER ACQUISITION RADAR AT CONCRETE, NORTH DAKOTA CAN DETECT OBJECTS AS SMALL AS 8 CENTIMETERS OR LESS. TESTS WITH THIS RADAR HAVE SHOWN A DEBRIS POPULATION BETWEEN 7 AND 35 PERCENT GREATER THAN THE CATALOGUED POPULATION. SOME OF OUR OPTICAL SENSORS CAN DETECT OBJECTS AS SMALL AS 1 CENTIMETER IN A LIMITED ZONE OF SPACE, DEPENDING ON THE TIME OF DAY AND THE REFLECTIVITY OF THE OBJECTS. THESE SENSORS HAVE DETECTED 8 TIMES THE NUMBER OF CATALOGUED OBJECTS.

THESE OBSERVATIONS ARE COMBINED WITH OTHER EVIDENCE, SUCH AS EXAMINATION OF THE SURFACES OF THE NASA SOLAR MAXIMUM SATELLITE AFTER ITS RETURN FROM ORBIT ON THE SHUTTLE. THE SOLAR MAX SURFACES SHOWED TWICE AS MANY IMPACTS FROM ORBITAL DEBRIS AS FROM NATURAL METEOROIDS. WHILE THEIR SMALL SIZE MITIGATES THE COLLISON HAZARD, THERE COULD BE BILLIONS OF SMALL DEBRIS PARTICLES, AROUND .1 MILLIMETER IN SIZE, IN LOW EARTH ORBIT.

WITH THIS BASIC AWARENESS OF THE NATURE AND DIMENSIONS OF THE PROBLEM, WE HAVE INTENSIFIED EFFORTS IN DOD TO UNDERSTAND THE HAZARD PRESENTED AND HOW TO COPE WITH IT. MUCH USEFUL WORK HAS BEEN DONE RECENTLY WITHIN THE U.S. SCIENTIFIC COMMUNITY TO CREATE MATHEMATICAL MODELS FOR MEASUREMENT OF SPACE DEBRIS AND TO DESIGN SOFTWARE FOR COMPUTER ANALYSIS AND PREDICTION OF TRENDS.

WE ARE USING ALL OF THIS INFORMATION TO EVALUATE THE RISKS ASSOCIATED WITH SPACE DEBRIS AFFECTING PRESENT AND FUTURE SPACE SYSTEMS THAT SUPPORT MILITARY OPERATIONS. AT PRESENT, THE HAZARD IS RELATIVELY MINOR. THE PROBABILITY OF COLLISION BETWEEN OUR SPACECRAFT AND OBJECTS OF SUFFICIENT SIZE TO DAMAGE THEM IS EXTREMELY LOW WITHIN THE OPERATIONAL LIFETIME OF THE SPACECRAFT. HOWEVER, THE TRENDS ARE DISTURBING.

EVEN THE MOST CONSERVATIVE ESTIMATES SHOW A STEADILY INCREASING HAZARD OVER THE NEXT 10 OR 20 YEARS. THOSE ESTIMATES DO NOT TAKE FULL ACCOUNT OF FUTURE USE OF LARGE SPACE STRUCTURES, NOR OF THE AMBITIOUS SOVIET SPACE PROGRAM, AND THE EMERGENCE OF NEW SPACEFARING NATIONS. THESE FACTORS WILL COMPOUND THE PROBLEM. FURTHER, THERE IS EVIDENCE THAT THE GROWING POPULATION OF MICRO-METEORITE-SIZE PARTICLES THAT WE CANNOT DIRECTLY OBSERVE COULD OVER TIME DEGRADE OR DAMAGE SOME SPACE SUBSYSTEMS. SOME OF THESE SUBSYSTEMS, SUCH AS SOLAR ARRAYS, ARE DIFFICULT IF NOT IMPOSSIBLE TO PROTECT.

SINCE 1981, THE SOVIET UNION'S PROPORTIONAL SHARE OF DEBRIS IN SPACE HAS RISEN DRAMATICALLY. MOREOVER, THE RATE OF ITS LAUNCH ACTIVITY AND THE SIZE OF ITS PAYLOADS IS CLEARLY ON THE RISE. IN ADDITION, EUROPE AND CHINA HAVE ALREADY COMMENCED REGULAR LAUNCH PROGRAMS; JAPAN, INDIA AND OTHER NATIONS WILL SOON FOLLOW. SPACE DEBRIS IS WITHOUT DOUBT AN INTERNATIONAL PROBLEM, BOTH IN CAUSE AND CONSEQUENCES.

WHILE WE CANNOT SOLVE THE PROBLEM OF SPACE DEBRIS WITHOUT THE COOPERATION OF OTHER NATIONS, THE UNITED STATES, IN THE MEANTIME, SHOULD ADDRESS THE PROBLEM AS A NATION, BOTH TO PROTECT OUR SPACECRAFT AND TO AMELIORATE THE SITUATION AS MUCH AS POSSIBLE. THE NATIONAL SPACE POLICY ON SPACE DEBRIS IS A FRAMEWORK FOR SUCH POSITIVE ACTIONS.

IN REGARDS TO PROTECTING OUR SPACECRAFT, THERE ARE THREE BASIC MEANS TO COPE WITH THE MOUNTING PRESENCE OF DEBRIS IN LOW EARTH ORBIT: FIRST, WE CAN SHIELD SATELLITES AGAINST SMALL OBJECTS; SECOND, WE CAN ADD DETECTION AND MANEUVER CAPABILITY TO SPACE SYSTEMS FOR AVOIDANCE OF LARGE, TRACKABLE OBJECTS; THIRD, AND FAR MORE PROBLEMATIC, THERE IS THE POSSIBILITY OF CLEANING UP THE SPACE ENVIRONMENT.

OF THESE APPROACHES, SHIELDING IS PROBABLY THE MOST FEASIBLE, NEAR-TERM PROTECTIVE MEASURE. ADVANCES IN SHIELDING TECHNOLOGY MAY HELP US KEEP PACE WITH THE PROBLEM. WE MAY BE ABLE TO SIGNIFICANTLY INCREASE THE DEGREE OF PROTECTION BY SHIELDING, USING NEW COMPOSITE MATERIALS IN LAYERS OR ARRANGED AS SUCCESSIVE BARRIERS. ON THE OTHER EXTREME, THE IDEA OF SWEEPING DEBRIS OUT OF ORBIT REMAINS A REMOTE TECHNOLOGY CHALLENGE. AT THE LEAST, IT MAY BE POSSIBLE IN THE FUTURE TO DE-ORBIT THE LARGEST PIECES OF SPACE DEBRIS SUCH AS EXPENDED ROCKET BODIES.

OF COURSE, THESE PROTECTIVE MEASURES ARE PALLIATIVE ONLY, AND WILL ONLY BUY US SOME TIME. AS OUR POLICY STATES, WE RECOGNIZE IN DOD THE NECESSITY OF PREVENTIVE ACTIONS TO MINIMIZE THE CREATION OF SPACE DEBRIS IN THE FIRST INSTANCE. THIS WILL BE DONE ON A CASE-BY-CASE BASIS, IN THE DESIGN OF SYSTEMS AND IN THE PLANNING OF SPACE TESTS AND OTHER SPACE ACTIVITIES. EFFECTIVE PREVENTIVE ACTIONS CAN BE IMPLEMENTED WITHOUT

ADVERSELY EFFECTING SPACE PROGRAMS THAT ARE IMPORTANT TO OUR NATIONAL SECURITY.

THE DELTA 180 EXPERIMENT CONDUCTED FOR THE SDI IS A GOOD EXAMPLE. IN THE FINAL STAGES OF THE EXPERIMENT, THE DELTA 180 PAYLOAD VEHICLE WAS DIRECTED TO COLLIDE WITH AN INSTRUMENTED TEST VEHICLE, PRIMARILY TO ASSESS THE ON-BOARD, AUTONOMOUS SENSORS AND TRACKING SYSTEMS. THE EXPERIMENT WAS ORCHESTRATED SO THAT THE COLLISION OCCURRED AT LOW ALTITUDE, APPROXIMATELY 120 NAUTICAL MILES. OUR SPACE SURVEILLANCE NETWORK IMMEDIATELY DETECTED THE DEBRIS FROM THE EXPERIMENT. AND, WE HAVE CONFIRMED THAT NEARLY ALL OF THIS DEBRIS RE-ENTERED THE ATMOSPHERE AND BURNED UP WITHIN 180 DAYS. WE CONSIDER THIS EXPERIMENT A SUCCESSFUL DEMONSTRATION OF OUR ABILITY TO MINIMIZE THE CREATION OF SPACE DEBRIS. CLEARLY, IT IS POSSIBLE TO CONDUCT TESTS OF THIS TYPE WITHOUT SIGNIFICANTLY ADDING TO THE PROBLEM OF SPACE DEBRIS.

ADMITTEDLY, ALTHOUGH WE HAVE BEEN THINKING SERIOUSLY ABOUT THIS PROBLEM FOR SOME TIME, WE ARE STILL AT AN EARLY STAGE IN THE DEVELOPMENT OF REMEDIAL POLICIES AND PRACTICES. IN ADDITION, THE IMPLEMENTATION GUIDELINES OF THE NATIONAL POLICY CALL FOR AN INTERAGENCY STUDY ON SPACE DEBRIS, CO-CHAIRED BY NASA AND DOD, UNDER THE OVERSIGHT OF THE NSC STAFF. THE STUDY TEAM IS DIRECTED TO MAKE SPECIFIC RECOMMENDATIONS FOR AN EFFECTIVE, GOVERNMENT-WIDE POLICY IN

THIS AREA, AND ALSO TO PROPOSE METHODS TO DEAL WITH THE PROBLEM INTERNATIONALLY.

WE HAVE AN APPROVED TERMS OF REFERENCE FOR THIS STUDY AND A DEADLINE FOR COMPLETION IN DECEMBER OF THIS YEAR. WE HAD OUR ORGANIZATIONAL MEETING LAST WEEK, AND I CAN REPORT THAT THE EFFORT HAS BEEN INAUGURATED WITH DETERMINATION TO PRODUCE USEFUL RESULTS. WE WILL BEGIN THE PROCESS BY POOLING OUR INFORMATION ON THE SUBJECT AND BY BRINGING OUR EXPERTS TOGETHER AT THE JOHNSON SPACE CENTER IN HOUSTON FOR DEDICATED WORK ON SPACE DEBRIS. THEY WILL BE INSTRUCTED TO PROVIDE A BASELINE FOR CONSIDERATION BY THE INTERAGENCY GROUP THAT HAS COGNIZANCE OF THIS MATTER. IT. THIS WILL BE AN EXCELLENT EXAMPLE OF INTERAGENCY COOPERATION IN WORKING TOGETHER EFFECTIVELY TOWARD COMMON GOALS.

TO CONCLUDE, DOD HAS BEEN IN THE FOREFRONT IN CALLING NATIONAL ATTENTION TO THE PROBLEM OF SPACE DEBRIS, AND IN TAKING STEPS TO AMELIORATE THE SITUATION. WE BELIEVE THAT AS A NATION, THE UNITED STATES CAN STAY AHEAD OF THIS PROBLEM, WITH ONE CAVEAT. ULTIMATELY, ALL SPACEFARING NATIONS MUST ACKNOWLEDGE SHARED RESPONSIBILITY. ALL MUST ADOPT SENSIBLE PRACTICES TO MINIMIZE THE CREATION OF PERSISTENT SPACE DEBRIS. IN THE UNITED STATES, WE HAVE ALREADY ESTABLISHED A SOUND POLICY BASIS TO DEAL WITH THE PROBLEM. WE HAVE BEGUN AN INTENSIVE, INTERAGENCY PROCESS TO BROADLY IMPLEMENT THAT POLICY ACROSS ALL U.S. SPACE SECTORS. AFTER PROPER STUDY OF THE WORLD SITUATION AND

ALTERNATIVE APPROACHES, IT IS LIKELY THAT WE WILL ALSO INITIATE INTERNATIONAL DISCUSSIONS TO ENLIST THE COOPERATION OF OTHER SPACEFARING NATIONS.

THANK YOU FOR YOUR ATTENTION.

DoD SPACE POLICY
SPACE DEBRIS

"DoD will seek to minimize the impact of space debris on its military operations. Design and operations of DoD space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements."

February 1987

IG (SPACE) ORBITAL DEBRIS WORKING GROUP
TERMS OF REFERENCE

- Define the Space Debris Problem
- Review and Assess Existing Legal Regime Regulation, Policies, and Activities
- Propose Approaches to Reduce the Problem
- Consider How to Approach Other Governments
- Identify Necessary Research
- Consider How to Implement the Policy

Mr. NELSON. Okay. We will get into a number of questions.

Mr. Michaud, your summary, please.

Mr. MICHAUD. Thank you, Mr. Chairman.

Like the other agencies represented at this table, we have been concerned about the debris issue for some years now. It has arisen in several international fora, particularly those associated with the International Telecommunication Union and the United Nations Committee on the Peaceful Uses of Outer Space. It has also been raised in the context of Intelsat.

We are also concerned because, as you mentioned in your opening remarks, the United States and its allies are going to deploy the largest object ever put into orbit, which is the space station. We also will soon resume Space Shuttle flights which will carry not only American astronauts but foreign payload specialists on some occasions. We are also aware of the fact that some foreign governments are concerned about the issue and have begun to look at it.

With these things in mind, we convened an Interagency Space Debris Group in 1986 to begin looking at the issue on an interagency basis. Defense and NASA had already done a considerable amount of work internally, but there was at that time no interagency forum for all of the interested agencies to look at the problem. That fed into the National Space Policy Study which, as you know, produced a very useful statement on space debris.

We believe debris is inherently an international issue. It does not respect national boundaries. The United States cannot solve the problem alone, and it will have to consult with other nations, particularly those that operate space systems.

If the Department of State is going to act effectively in its bilateral relations or in its representation at international organizations, we have to have a consensus behind us as to what our policy should be on debris, and that is going to be a central issue that is going to be addressed in the National Space Review of Space Debris that Mr. Kunsberg mentioned.

We will be looking at the question of how to approach foreign governments; we will be looking at the question of what it is we are going to ask them to do. While it would be premature to get into specifics, our general preference is that we should begin with those States which actually conduct space operations and those organizations, like the European Space Agency, which are actively engaged in space operations.

We will also need to provide more detailed guidance to our representatives at international organizations. For example, the SpaceWARC, which is going to begin meeting at the end of next month, has on its agenda, among many other items, a report from the CCIR on the space debris issue.

We are aware of the fact that many solutions have been proposed to the space debris problem, both technical and regulatory. We will be looking at these proposals in the space debris study. We will have to look at the consequences of those solutions for our civil, defense, and commercial space programs.

Until that study is done, we would take the position, both domestically and internationally, that it would be premature to attempt to legislate or impose either technical or regulatory solutions to the

debris problem. In short, Mr. Chairman, we need to get our act together first.

Thank you, and I'd be happy to answer any questions.

[The prepared statement of Mr. Michaud follows:]

STATEMENT OF
MICHAEL A.G. MICHAUD
DIRECTOR, OFFICE OF ADVANCED TECHNOLOGY
DEPARTMENT OF STATE
BEFORE THE
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS
U.S. HOUSE OF REPRESENTATIVES

JULY 13, 1988

MR. CHAIRMAN, THANK YOU FOR INVITING THE DEPARTMENT OF STATE TO TESTIFY ON THE IMPORTANT SUBJECT OF SPACE DEBRIS.

MY DEPARTMENT HAS BEEN INTERESTED IN THIS ISSUE FOR SOME TIME. U.S. REPRESENTATIVES HAVE ENCOUNTERED EXPRESSIONS OF CONCERN AND PROPOSALS FOR ACTION ON SPACE DEBRIS IN BODIES ASSOCIATED WITH THE INTERNATIONAL TELECOMMUNICATION UNION, AS WELL AS EXPRESSIONS OF INTEREST IN THIS SUBJECT IN THE UNITED NATIONS COMMITTEE ON THE PEACEFUL USES OF OUTER SPACE, THE CONFERENCE ON DISARMAMENT, AND THE INTERNATIONAL TELECOMMUNICATIONS SATELLITE ORGANIZATION. MOST RECENTLY, IN THE SPECIAL SESSION OF THE U.N. GENERAL ASSEMBLY ON DISARMAMENT, HELD IN NEW YORK IN MAY AND JUNE OF THIS YEAR, SOVIET FOREIGN MINISTER SHEVARDNADZE SAID THERE WAS A NEED TO EXPLORE POSSIBILITIES FOR RULES AND PROCEDURES TO PREVENT "POLLUTION" IN OUTER SPACE. WE ALSO ARE AWARE OF THE INTEREST IN THIS ISSUE SHOWN BY SOME FOREIGN SPACE AGENCIES.

IN ADDITION, SINCE 1985 THE DEPARTMENT HAS BEEN LEADING THE U.S. SIDE IN THE NEGOTIATION OF INTERGOVERNMENTAL AGREEMENTS GOVERNING THE PARTICIPATION OF OUR FOREIGN PARTNERS IN THE SPACE STATION. WHEN DEPLOYED, THE SPACE STATION WILL HAVE THE

LARGEST CROSS-SECTION OF ANY OBJECT HUMANS HAVE PLACED IN ORBIT, AND IT WILL BE CONTINUOUSLY MANNED BY CREWS THAT WILL OFTEN INCLUDE FOREIGN PERSONNEL. THE RENEWAL OF SPACE SHUTTLE FLIGHTS WILL AGAIN PLACE U.S. CREWS, AND OCCASIONALLY FOREIGN PAYLOAD SPECIALISTS, INTO ORBIT. WE THEREFORE HAVE BELIEVED FOR SOME TIME THAT THE ISSUE OF SPACE DEBRIS DESERVES SERIOUS CONSIDERATION.

A KEY REASON FOR THE DEPARTMENT'S INTEREST IS THAT THE ISSUE IS OF GROWING CONCERN TO OTHER GOVERNMENTS, PARTICULARLY TO OUR FRIENDS AND ALLIES, WHO LOOK TO US TO PROVIDE LEADERSHIP ON SUCH ISSUES. AT THE SAME TIME, THE ABILITY OF THE DEPARTMENT OF STATE TO ACT EFFECTIVELY INTERNATIONALLY ON THIS ISSUE WILL BE VERY CONSTRAINED UNTIL THERE IS A CONSENSUS ON THE NATURE OF THE PROBLEM AND ON THE APPROPRIATE STEPS TO DEAL WITH IT. WE NEED TO IDENTIFY AT THE NATIONAL LEVEL WHAT OUR POLICY WILL BE AND THEN TO SEEK INTERNATIONAL SUPPORT. AND, I WOULD NOTE HERE THAT A KEY ASPECT OF WHAT WE WORK OUT AT THE NATIONAL LEVEL WILL HAVE TO BE BASED ON CLOSE CONSULTATIONS WITH THE U.S. PRIVATE SECTOR. WE DO NOT WANT TO BE IN THE POSITION OF HAVING NOTHING CONSTRUCTIVE TO SAY IN INTERNATIONAL DISCUSSIONS ON SPACE DEBRIS.

IN 1986, THE DEPARTMENT OF STATE CONVENED AN Ad Hoc INTERAGENCY WORKING GROUP ON SPACE DEBRIS. OVER THE FOLLOWING YEAR, THE GROUP RECEIVED BRIEFINGS FROM NASA EXPERTS AND HELD

PRELIMINARY DISCUSSIONS ON THE ISSUES. A GENERAL CONSENSUS DEVELOPED THAT THE SPACE DEBRIS PROBLEM DESERVED POLICY ATTENTION AT THE NATIONAL LEVEL.

WHEN THE NATIONAL SPACE POLICY REVIEW COMMENCED IN JULY 1987, WE SUSPENDED THE ACTIVITIES OF THE AD HOC INTERAGENCY GROUP, AS SPACE DEBRIS WAS ONE OF THE MANY ISSUES TO BE ADDRESSED IN THE REVIEW. AS YOU KNOW, MR. CHAIRMAN, THE SPACE POLICY DOCUMENT SIGNED BY THE PRESIDENT IN JANUARY, 1988 CONTAINS THE FIRST EVER U.S. NATIONAL POLICY STATEMENT ON SPACE DEBRIS. THE DEPARTMENT OF STATE FULLY SUPPORTS THAT STATEMENT, AND BELIEVES THAT IT PROVIDES A SOUND FOUNDATION FOR THE DEVELOPMENT OF MORE SPECIFIC APPROACHES TO SPACE DEBRIS ISSUES. THE FURTHER DEVELOPMENT OF POLICIES IN THIS AREA WILL BE ADVANCED BY AN INTERAGENCY STUDY BEING LED BY NASA AND THE DEPARTMENT OF DEFENSE.

MR. CHAIRMAN, WE SEE SPACE DEBRIS AS AN INHERENTLY INTERNATIONAL ISSUE. ORBITAL SPACE DEBRIS DOES NOT OBSERVE NATIONAL BOUNDARIES. SEVERAL NATIONS AND ORGANIZATIONS HAVE CONTRIBUTED TO THE DEBRIS PROBLEM THROUGH THEIR SPACE ACTIVITIES, AND THE DYNAMICS OF ORBITAL DEBRIS LEAD TO THE INTERMIXING OF DEBRIS FROM DIFFERENT OPERATORS. ANY SPACECRAFT FROM ANY NATION COULD SUFFER FROM THE EFFECTS OF SPACE DEBRIS; NONE OF US IS IMMUNE. IT MAKES LITTLE SENSE FOR THE UNITED STATES TO TRY TO SOLVE THE PROBLEM OF ORBITAL DEBRIS BY

ITSELF, IN ISOLATION FROM OTHER NATIONS AND ORGANIZATIONS WHICH OPERATE IN SPACE. WE ARE ALL IN THIS TOGETHER. SOONER OR LATER, WE WILL NEED TO CONSULT WITH OTHERS.

THE QUESTION OF HOW AND WHEN TO APPROACH FOREIGN GOVERNMENTS WILL BE ADDRESSED IN THE INTERAGENCY SPACE DEBRIS STUDY. AS THAT STUDY IS ONLY NOW GETTING UNDER WAY, IT WOULD BE PREMATURE FOR ME TO GET INTO SPECIFICS. HOWEVER, I WOULD NOTE MY DEPARTMENT'S GENERAL VIEW THAT, ONCE U.S. POLICY ON SPACE DEBRIS IS ESTABLISHED, OUR FIRST PRIORITY SHOULD BE TO CONSULT WITH GOVERNMENTS AND ORGANIZATIONS THAT ACTUALLY CONDUCT OPERATIONS IN SPACE, BEGINNING WITH OUR FRIENDS AND ALLIES. WE WILL ALSO NEED TO CONTINUE PROVIDING GUIDANCE TO OUR REPRESENTATIVES TO INTERNATIONAL ORGANIZATIONS, AND THAT ISSUE TOO WILL BE ADDRESSED IN THE INTERAGENCY STUDY.

IN THAT STUDY, WE ALSO WILL BE LOOKING AT THE RELEVANCE OF DOMESTIC AND INTERNATIONAL LAW TO SPACE DEBRIS. WHILE THERE IS NO SPECIFIC INTERNATIONAL LEGAL INSTRUMENT APPLYING TO SPACE DEBRIS, THERE IS A LEGAL REGIME FOR OUTER SPACE WHICH CONTAINS RELEVANT PROVISIONS.

A FINAL NOTE, MR. CHAIRMAN. A NUMBER OF PROPOSALS HAVE ALREADY BEEN MADE FOR TECHNICAL AND REGULATORY APPROACHES TO THE SPACE DEBRIS PROBLEM. WE WILL BE LOOKING AT SUCH PROPOSALS IN THE INTERAGENCY STUDY. IN THE MEANTIME, WE WOULD URGE THAT NO LEGISLATION BE ENACTED THAT WOULD PRE-EMPT THE RESULTS OF THAT STUDY BY IMPOSING SPECIFIC TECHNICAL OR REGULATORY

REQUIREMENTS. AS WE HAVE NOTED IN INTERNATIONAL FORA, AS WELL, PREMATURE ACTIONS THAT DO NOT TAKE INTO ACCOUNT ALL THE INTERESTS INVOLVED COULD DO MORE HARM THAN GOOD.

THANK YOU FOR YOUR ATTENTION. I WOULD BE PLEASED TO RESPOND TO ANY QUESTIONS THE SUBCOMMITTEE MAY HAVE.

Mr. NELSON. And your act, of course, is very important, because, you know, a lot of the debris comes from other nations.

Mr. MICHAUD. Absolutely right.

Mr. NELSON. And basically we can't tell them what to do; we have to negotiate with them and show them why it's clearly in their interest as well, and that, in large part, depends on your agency, the Department of State.

Mr. Stadd, your summary, please.

Mr. STADD. Thank you, Mr. Chairman.

Mr. Chairman, it comes as no surprise to the committee that since the Congress gave us some very fundamental public safety regulatory responsibilities in 1984 in the commercial space transportation area, that the Department has taken the risks associated with orbital debris quite seriously these past years, and beginning in '84 we have begun talking and exploring the issue with the agencies here at the table.

As my testimony details, there are governmental mechanisms that already exist to inventory and suggest collision avoidance techniques and so forth, and we also factor that into our licensing procedures.

I do want to remind the committee, however, that although the FCC, for example, has responsibility for regulating the communications satellite operations by assigning radio frequencies and so forth, it is not charged with protecting the physical safety of satellites in orbit, and that responsibility has traditionally been borne, Mr. Chairman, by either the sponsoring agency or the satellite owner who monitors the status of the operation.

At present, the Department is the only agency with the specific statutory authority to prohibit a commercial launch of a vehicle or a payload in the event it is determined that that launch operation or payload would jeopardize public health or safety or the safety of the property involved.

Let me give the committee two or three instances of what we are concerned with in the licensing process. Again, I detail it more in the actual formal testimony.

When an applicant comes into the office, our concerns range from the historical experience that that operator has had with staging and orbital insertion activities; we are concerned in that regard with parking and transfer orbits; we are concerned with steps they are taking and have taken to mitigate the safety of risks associated with orbital operations, and so forth.

Now I will also bring to your attention that there was an AIAA—American Institute of Aeronautics and Astronautics—paper that came out in '81 with a fundamental theme, and it said that the prevention of space debris is more practical and more cost-effective than active after-the-fact controls. So to the degree permitted by current levels of technology and expertise, the Department, through its licensing reviews, is seeking to approach this effort in just that manner.

We are also actively engaged in research aimed at defining the regulations and how we can improve our licensing decisions, and I believe the committee has been provided with copies of our Hazards Analysis that we recently released. This looks at virtually every aspect of the potential hazards of commercial launches upon

vital national interests, including safety operations, rocket safety characteristics, and so forth.

We have also just completed a study, Mr. Chairman—it is still in draft form—of the orbital safety hazards, with particular emphasis on the policy issues of interest and the licensing of commercial launches, and I'll make that available to the committee as soon as that is releasable.

Perhaps the most critical procedure, I think, the Department brings to solving the problem of debris production and the hazards it poses is our license applications, as I said earlier, and I can assure the committee that each application is subject to a rigorous review of the hazards involved, and I'd also like to submit for the record a copy of the analysis we went through with the recent McDonnell-Douglas licensing of their INSAT 1D, and that will give the committee a pretty good picture of what we go through in our analysis.

Finally, as has been stated here, we are a very active member of this Interagency Task Force, and we look forward to sharing the results of that with the committee when completed.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Stadd follows:]

Statement of

Courtney A. Stadd
Director, Office of Commercial Space Transportation
U.S. Department of Transportation

before the

Subcommittee on Space Science and Applications
Committee on Science, Space and Technology
U.S. House of Representatives

July 13, 1988

Mr. Chairman, members of the subcommittee, thank you for this opportunity to comment on the issue of space debris and its implications for the nation's commercial space program.

DOT has been looking at the issue of orbital debris since 1984, when it took on responsibility for regulating commercial space launches. At that time, we met with officials from NASA, DOD, and other experts in the fields of space debris and orbital hazards to determine the nature and extent of the problems that were caused by and could be expected from increasing levels of on-orbit debris. We also looked at the measures that had been adopted to mitigate its effects.

Government agencies (NASA, DOD, and NOAA) have responsibility for taking whatever steps they deem necessary and appropriate to minimize the amount of debris created by their space operations. These agencies realized some time ago that debris generated by their launch and on-orbit activities posed a significant threat to the success of future operations.

In addition to the effect of orbital debris on America's civil and military space programs, the problem has significant implications for space commerce. Spent rocket stages in low earth orbit account for some of the debris currently being tracked by DOD. Accidental explosions of residual fuel left in spent stages have exacerbated the problems caused by floating hardware. As the

level of debris increases, so does the likelihood that it will cause on-orbit collisions, destroying satellites or seriously impairing their operation. This is true both for debris in low earth orbit, as well as for debris in geosynchronous orbit, where its effects are most persistent. Commercial operators of launch vehicles and satellites alike are deeply concerned with both the causes and the effects of orbital debris.

Some government mechanisms already exist to deal with the space debris problem. The national ranges, for example, are responsible for ensuring the safe operation of a launch through the first orbit. The U.S. Space Command and the ranges have a variety of analysis and control tools to assist them in this function. Two such tools are Collision Avoidance on Launch (COLA), which helps identify safe launch windows, and Computation of Miss Between Orbits (COMBO), to determine the optimal orbit to ensure that it will not collide with satellites already in orbit, while still accomplishing its mission.

Among the organizations that can assist these entities in their efforts to safeguard their payloads is the Satellite Control Facility, which checks the status of the various U.S. satellites (both government and commercial) by calling the operators periodically to update their status. The Satellite Surveillance Network monitors the inventory of new space objects. These organizations may be able to anticipate possible collisions between objects, but it is the operators' responsibility to maneuver a satellite out of position when notified of a close approach.

Although the FCC has responsibility for regulating communications satellite operations by assigning orbital slots and radio frequencies, it is not charged with protecting the physical safety of satellites in orbit. That responsibility has heretofore been borne by the sponsoring agency or satellite owner, who monitors the status of the operation.

At present, DOT is the only agency with specific statutory authority to prohibit a commercial launch of a vehicle or payload in the event it is determined that that launch operation or payload would jeopardize public health and safety or the safety of property. The commercial space launch licensing process reflects DOT's concern that commercial launch companies address the safety issues associated with their operations, including the creation of orbital debris. Both phases of our license application review process, the mission and safety reviews, include orbital safety assessments of:

- o the launch vehicle stages and its payload, including evaluations of mission hardware reliability and safety performance;
- o mission planning and ELV design;
- o parking and transfer orbits for spent rocket stages,
- o evaluations of the orbital life of spent stages and the probable impacts during reentry;
- o collison probability with active payloads that could be jeopardized by the debris of the mission under review;
- o safety of orbital operations -- for example, the venting of residual propellants in rocket stages after orbital operation -- to minimize the likelihood of explosions;
- o the types, likelihood, and consequences of on-orbit failures of ELV launch and space missions licensed by the Department.

In a 1981 position paper on space debris, the American Institute of Aeronautics and Astronautics stated that the prevention of space debris is more practical and more cost-effective than active, "after-the-fact" controls. To the degree permitted by current levels of technology and expertise,

the Department, through licensing reviews that evaluate each launch project by the above criteria, seeks such prevention.

We are also actively engaged in research aimed at defining these regulations and improving our licensing decisions, by looking at both ELV design features and at on-orbit practices that could minimize creation number of mission-related pieces of orbital debris and mitigate their hazards. One hazard is the creation of new orbital debris by collisons in space. Vehicle design features aimed at avoiding this include so-called "litter-free" ELVs that minimize the number of discarded hardware pieces. Selection of parking and geotransfer orbits for earliest possible reenty is another remedial approach. Debris-minimizing designs and operational practices obviously include those that make explosions and collisions unlikely, or that confine explosion debris to low Earth orbit so that resultant debris can reenter as quickly as possible. Another possible operational practice is managing launch and orbital maneuvering times in order to facilitate rapid degradation of geotransfer orbit and early reentry to Earth's atmosphere.

The ELVs now being offered on a commercial basis were developed by and for the United States government; therefore, DOT has not imposed more restrictions and controls than are currently practiced by government itself. We can and should, however, work with NASA and DOD in conducting cost-effectiveness research to determine whether additional restrictions are feasible.

Three Departmental evaluation efforts have addressed the problem of reducing the commercial sector's contribution to the incidence and effects of space debris. Recently, we issued a three-volume study, Hazards Analysis of Commercial Space Transportation, which looks at virtually every aspect of the potential hazards of commercial launches upon vital national interests, including range safety and operations, rocket safety characteristics, public risk exposure, and notably, the hazards resulting from orbital collisions and reentry.

We have also just completed a study, still in draft form, of orbital safety hazards with particular emphasis on the policy issues of interest in the licensing of commercial launches. Among other issues, this study looks at the relative amount of debris generated by different classes of domestic ELVs.

Perhaps the most critical procedure DOT brings to solving the problem of debris production and the hazards it may pose is our license application evaluation process. Each application is subject to a rigorous review of the hazards, including the hazards from debris, its launch or payload could pose.

We are also a member of the National Security Council's Interagency Working Group on Space Debris. Chaired by NASA and DOD, this task force will implement the National Space Policy directive that all space sectors minimize the creation of space debris consistent with their mission requirements and cost effectiveness.

DOT's contribution to the task force will include the formulation of recommendations vis-a-vis commercial launch operations that reflect the national space policy guideline to regulate commercial launch activities only to the extent required by law, which includes national security, international obligations, and public safety.

The Department welcomes the opportunity to carry out its role in contributing to the nation's spacefaring capabilities by working with the commercial sector to increase our access to space while minimizing the amount and effects of orbital debris this access could create.

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ON-ORBIT RISK ASSESSMENT
FOR
MCDONNELL DOUGLAS LICENSE APPLICATION MDC/006

DEPARTMENT OF TRANSPORTATION
OFFICE OF COMMERCIAL SPACE TRANSPORTATION
LICENSING PROGRAMS DIVISION

May 20, 1988

Dr. Aviva Brecher, Safety and Security Systems

DOT/ Transportation Systems Center
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May 25, 1988

AN ASSESSMENT OF ON- ORBIT AND RE- ENTRY HAZARDS FOR THE DELTA/ INSAT MISSION

1. SPACE ORBITAL ENVIRONMENT

This section describes the orbital environment of the launch staging and orbital insertion for the McDonnell Douglas (MDAC) Delta 4925/ INSAT 1-D satellite launch from the Eastern Space and Missile Center (ESMC). Of particular concern for the DOT Office of Commercial Space Transportation (OCST) is the assessment of orbital collision probabilities of the second (2nd) and third (3rd) rocket stages, after normal jettison in orbit, with other US Government, foreign, or commercial active payloads. Also of interest are the numbers, and types of space objects potentially at risk from either normally orbiting and decaying Delta stages, or from the premature re-entry of failed stages and/or payloads, as a result of orbital insertion failures. For on-orbit accident scenarios the land impact probabilities of re-entry debris contribute to the total casualty expectation. Thus, the orbital environment description can assist OCST in evaluating normal, or accidental on- orbit and re-entry risk levels, in order to determine appropriate liability coverage to be carried by MDAC, the time period for such coverage after launch, and reasonably expected property damage levels in space and on the ground, as a result of on-orbit collisions.

Accidental failures in the orbital phase of the mission could lead to unanticipated orbital collision hazards; and to premature re-entry of stages, and possibly of the payload, and thus to population centers on the ground The MDAC License Application indicates in Fig.1-10 (Mission Profile) that the Delta 2nd stage, with attached 3rd stage and payload, achieves parking orbit at SECO 1 (702 sec after launch), coasts to restart, SECO 2 is at 1280 sec; and after 3rd stage ignition (1376 sec), the separated 2nd stage coasts until it performs a depletion burn at 4800 sec. The 3rd stage burnout occurs at 1462 sec, and the spacecraft separates at 2662 sec. Therefore, for any accidental deviations from nominal mission, the "orbital " phase of operations of interest for this assessment spans the 702 sec to 2662 sec, i.e. the roughly 30 min long time interval for orbital maneuvers, between SECO 1 in parking orbit, and payload separation in GTO.

MDAC is responsible for the launch and on-orbit operations up to the point of payload separation in GTO. The two orbits of interest to the OCST orbital safety assessment are: a) the parking circular orbit at 185 km (100 nmi) of the expended second stage, in which the 3rd stage spin-up, separation and burn also takes place in order to achieve a geo- stationary transfer orbit (GTO) ; and b) the elliptical GTO orbit, with a 100 nmi perigee and a 19,323 nmi (35,747.5 km) apogee. On page 2-9 of the LicenseApplication, Book 1 (Reference 1 A), MDAC states that the "Delta 2nd stage achieves and remains in a 100 nmi parking orbit during its burn period. The

Delta 3rd stage achieves and remains in a 100x 19,323 nmi GTO during its entire life in orbit".

As explained in Ch. 6 of the Hazard Analysis Report (Reference 2), the orbital collision probabilities (per period, or normalized to some other unit of interest, per year, or per operational lifetime in orbit) are proportional to the product of the object's cross- section (size), by the spatial density of objects at a certain altitude range, and by the transit time through that region of space.

It must also be noted that while only 5 % of all orbiting space objects are active satellites that may be at risk from an orbital collision, the fraction for geo-synchronous earth orbit (GEO) is 20 %, based on the fact that 116 out of a total 543 communication satellites in orbit are presently active. Moreover, the probability of orbital collision is proportional not only to the spatial number density of objects in a certain altitude range, and within a certain inclination range, but also to the time that the object spends in that "bin". Because there are favored orbits and missions, the spatial object distribution is quite lumpy: For the case of near collisions (< 50 km miss distance) in GEO monitored over 6 months by the USAF Satellite Control Facility (SCF) (discussed in Ch. 6, Ref.2), the near-collision probability observed was nearly 100 times greater than expected based on the average population and relative orbital velocities in GEO.The SCF monitors the operational status of US satellites and the orbital close approaches, using the COMBO (Computation of Miss Between Orbits) code, and may command and implement orbital maneuvers in the unlikely event of a close approach (within 10-100 km) and a near- collision on-orbit (see Reference 3).

To date, there have been no reported and documented on-orbit collisions between active payloads, or of an orbiting active satellite with parked 2nd and 3rd stages, or with flight hardware debris (with two exceptions, in 1979 and 1980, when satellites collided with their own 3rd stages, after improper separation, Ref.2). Only two recent satellite malfunction events, now being analyzed by Teledyne Brown for US SPACECOM, are suspected to be due to orbital collisions (Refs.3,4). About thirty nine satellites are known to have broken up in orbit: 15% of fragmentation causes are propulsion- related, 40% were deliberate, and 45% (which generated 34% of all orbiting debris) are due to unknown causes, possibly to impacts with space debris. However, the present orbital tracking capability can not resolve between a hypervelocity impact with orbiting debris, and a deliberate explosion. Statistically, since only 5% of all orbiting objects in space are active payloads, only 5%x 45% of the 39 on-orbit satellite fragmentation events, i.e. less than one event could have been a satellite/satellite collision, while a satellite/ debris collision is 20 times more likely (see Ref.4). On- orbit collisions may, or may not lead to premature re-entry, depending on the orbital altitude, orbital lifetime, and the relative velocity of the colliding objects (see Section 2). Fragments and small debris are likely to burn-up during re-entry.

In over 30 years of government space operations todate, there have been only few and minor property damage claims but no injuries or deaths resulting from re-entry of natural and destruct debris impacts. Informal reports ascribe these re-entry debris damage incidents to mission failures, and not to normal uncontrolled re-entry. Debris, though often tracked by SPACECOM to ground impact, are apparently not recovered systematically (Ref.3). Occasional field recoveries of debris can rarely be clearly linked to a specific launch (see Ref.5), especially since debris from classes of launches from a given site (e.g. ESMC to typical GEO missions) often have similar orbits and similar mission hardware. Also, since the "rain-down"(gradual de-orbit)

of space debris, including spent upper stages, is accelerated when the Sun is more active, hardware from several missions may re-enter clustered in time.

Re-entries of artificial space debris are quite common: about 300-500 objects re-enter per year, predominantly from low earth orbits (LEO). About 70 % of the annual mass to orbit re-enters within 1 year after launch (including launch debris and 2nd stages), and 5% of the mass to orbit returns within 5 years from launch (see Ch. 7, Ref.2). Considering that only about 500 meteorites per year are estimated to impact the Earth, from the roughly 10, 000 meteors entering the atmosphere (i.e. a 5% survival rate by number, but probably much lower by mass), the present risk associated with artificial space debris is negligible and below the natural level.

Most of these re-entering space debris fragments from all sources (normal and accidental decay of rocket stages, flight hardware, and payloads) disintegrate and burn- up in the atmosphere, before reaching the ground (see Ref.4). The probability of personal injury from re-entering space debris was estimated to be lower than that from the natural meteorite background. A figure of the order of 1 in a thousand appears in Ref.4, but such a probability of casualty from artificial space debris seems high, given that billions of people, and thousands of launches and re-entries over the past 30 years have yet to cause a documented death, or an injury claim. While the average hazard level to populace due to re-entering space debris is quite low, the uncertainty in point of impact for uncontrolled re-entries can cause alarm, since a possible impact with a population center can not be predicted accurately, nor generally avoided (though see the discussion of maneuvers on Skylab to modulate its re-entry impact point, Ref.9).

Only if a tracking and impact prediction (TIP) message for a clearly identified payload, or stage, is sent out by the US Space Command (US SPACECOM) for a decay/ re-entry event with priority status, can any debris recovered be assigned to a launch event/vehicle/country. The USAF has apparently recovered re-entry debris only for selected Priority 1 TIP messages (i.e. objects massive enough to survive re-entry heating to ground impact), but these data are classified.

Therefore, any re-entry damage event can only be linked circumstantially and inferentially, and only rarely with any certainty, to a specific launch event. Therefore, it will be difficult to prove clear liability for both on-orbit collision damage to an active payload (which may be monitored at weekly intervals), and for re-entry impact damage on the ground.

The 2nd and 3rd stages do not remain in the designated parking and GTO orbits, but gradually,decay over periods from days to months to a few years, depending on atmospheric drag and solar activity levels. Impact hazards to people and property on the ground associated with uncontrolled re-entry from decaying stages, are further discussed below and in Reference 9. In addition, there are potential hazards to active payloads in orbits near to, or crossed by, the spent stages during their orbital life.

Delta 2nd stages in parking orbit are fairly large, with relatively high ballistic coefficients, and thus decay fairly rapidly, decreasing the probability of collision with an active payload in a low earth orbit.

The orbital lifetime in a circular 100 nmi orbit ranges from 1 day to 30 months (see Fig 7-1 a. in Ref.2), depending on the mass, drag coefficient and size of the object, as well as on the solar activity level. For an elliptical GTO type orbit, with periods of

about 6 hours, orbital life is of order 2,000 orbits, or less than 2 years. Indeed, the data on orbital lifetime and re-entry dates for 2nd and 3rd stages of Delta missions launched after 1982 in the Supplementary MDAC License Submittal to OCST (May 11, 1988, Ref.1B) confirms that of the eleven listed Delta missions with both 2nd and 3rd stages, only three 2nd stages are still in orbit (life 2-5 years), six 2nd stages re-entered within one year, while the three 3rd stages that re-entered came down after about 8 months to 3 years.(Note that Titan 2nd stages are larger, and are jettisoned typically at lower orbital altitudes of about 85 nmi, and thus decay faster and re-enter within a few days.)

The year 1982 is a demarcation point for the orbital safety impacts and risks of Delta 2nd stages: ten Delta 2nd stage spontaneous explosion events occurred on-orbit between 1973 and 1981 (see Table provided in Ref 6, and discussion in Ch. 2, Ref.4). These explosions were caused by thermally induced oxidizer tank overpressure, and have generated orbital debris representing about 1/3 of all debris currently in orbit (about 175 debris per event, 2/3 of which are still in orbit). As an orbital collision safety measure, NASA instituted in late 1981 a propellant venting policy (namely fuel depletion burn in parking orbit for spent Delta 2nd stages), which successfully eliminated further on-orbit explosions. The MDAC License Application (Ref.1 A) states on p. 2-7 that "in order to passivate the stage, the 2nd stage vehicle propellants are depleted with a cross-plane depletion burn, and the gas bottles are blown down. The depletion burn is performed over a ground tracking station in Hawaii to monitor the safing of the Delta stage".

Hence, while the probability of a collision of spent stages with operational payloads is presently considered negligibly small, the secondary debris from previously exploded Delta 2nd stages pose a greater on -orbit collision risk (see Ref.4).

For a GTO 3rd stage, only 3 % of the time is spent at GEO altitudes, where 20 % of the payloads are still active. Hence, the probability of a GTO 3rd stage and debris colliding with another operational satellite scales down by a factor of 6×10^{-3} the already low averaged spatial object densities typical of GEO (7×10^{-10} per km^3) and by 1.5×10^{-3} that of LEO (roughly 5×10^{-11} per km^3) Therefore, the main hazard to GEO satellites is not primary collisions with 3rd stages, which spend little time at GEO altitude, but the generation of any secondary debris in elliptical orbits, which could then cross GEO and endanger active satellites. This would have a cascading effect on increasing the GEO debris populations, since GTO debris pass through the GEO corridor at relatively high velocities.

The SSC (Satellite Surveillance Center) has been typically asked to perform COMBO (COmputation of Miss Between Orbits) runs to assure the orbital safety for Shuttle missions, and the Range (ESMC) runs COLA (COLlision Avoidance), to determine safe "event windows" for launch through one orbit. The COLA is run for a specified miss distance (typically 200 km), and with a safety margin (typically 4 minutes uncertainty in the time of arrival of a satellite at a prescribed point in space), added to account for uncertainty in the ephemerides in known satellites trajectories. The US SPACECOM provides- on request- orbital proximity screening (within 200 km to 25 km PCA passes) for the time interval spanning the first Second Engine Cut-Off (SECO) to the end of spacecraft orbital insertion maneuvers (see Refs 6 a and b). These recent Delta 180, 181 Orbital Safety Review Reports indicate that acceptable probabilities of orbital collision in LEO are of order 10^{-5} for unmanned, and 10^{-6} for manned, spacecraft.

What objects are orbiting in/near the regions of space where spent 2nd and 3rd stages are likely to sweep, and how many of these are active payloads, potentially at risk from collision on-orbit?

By using 3 different space objects catalogs (the Dec.' 87 NASA Satellite Situation Report (FATSAT), the SPACECOM Satellite Catalog (SATCAT), and the FAS 1987 " What's Up in Space"), one can get a fairly complete picture as to when various stages associated with specific GEO launches from ESMC re-entered, and what classes of objects orbit at/near 100 nmi, and/or are crossed by GTO transfer stages. From the NASA FATSAT, it appears that only transient, rapidly decaying jettisoned launch hardware are in the 100 nmi orbit. Typical STS missions for the orbiter are indeed at 150-250 km altitudes, at / near 23-28° inclinations of most ESMC launches. No active payloads are presently at risk from possible collisions with orbiting and decaying 2nd stages (except for future STS missions). To date, the STS has never had to perform avoidance orbital maneuvers.

The Soviet MIR Space Station and its companions (MIR QVANT-1, SOYUZ TM-3 and -4) typically orbit at/near a 335 km perigee x 358 km apogee, at higher inclination (51.6°) than is the case for ESMC launched spacecraft and stages (near 26.7°), or ESA launches from equatorial sites (near 6.5°). Most Soviet Low Earth Orbit missions have typically much steeper inclinations (46-85°) due to the higher latitude launch sites.

Because of the distinct inclinations signature for US launches from ESMC, it appears very unlikely that 2nd and 3rd stages of Delta commercial launches will collide with any active US or foreign, or commercial payloads. However, since no lists of orbiting payloads potentially at risk during the orbital life of the 2nd and 3rd stages have been provided as part of the MDAC license application (Refs 1 A,B), this is only a general comment. The COLA runs by the Range in support of the Delta mission launch and orbital safety screening, cover collision avoidance during launch and orbital insertion operations, plus the first orbit. Because the uncertainty in the position and orbital parameters of LEO satellites increases with time as the orbit decays, running COLA for longer time intervals prior to the mission would probably not enhance the orbital collision safety.

2. ON- ORBIT ACCIDENT TYPES AND CONSEQUENCES

In this section we identify and describe qualitatively - and, to the extent possible, quantitatively- the consequences of on-orbit failures/ accident types identified in the technical reports produced by/ for NASA in the Delta program (Refs. 7) and more recently by MDAC for the Air Force (Refs.8). Of interest for determining appropriate insurance requirements are estimates of the probability and extent of property damage on-orbit due to orbital collisions (in parking, GTO and transient accidental orbits), as well as on the ground; and property damage and injuries/ fatalities caused by land impacts from the inadvertant re-entry of mission hardware or destruct vehicle debris, in case of mission failure.

Early NASA risk assessments for Delta launches (Refs.7) included detailed analyses of gross functional failure modes (FMEA) for each mission and vehicle configuration, added all failure probabilities, and estimated their consequences, including both total land impact probabilities and casualty expectation (by country, from all failure modes over that country, and by mode) prior to mission approval. To our best knowledge, such studies have not been required for mission/ launch

approval since the mid-sixties; DOD has required an FMEA only for new flight hardware, or for deviations from flight-certified ELV configurations (Refs.8).

The Supplemental MDAC License Application (Ref.1B) contains in Table 2 a discussion of on-orbit failures types, their estimated probabilities of occurrence, and a qualitative statement on associated hazard level, by category. These, presumably independent, failure modes are:

- failure of 2nd stage restart, followed by normal 3rd stage burn;
- failure of 3rd stage ignition;
- loss of attitude control prior to/ during 2nd stage restart;
- loss of attitude control, or 3rd stage failure to spin-up, followed by 3rd stage burn;
- failure of 2nd stage to shut down when planned;
- early cut-off of 2nd , or 3rd, stage;
- loss of attitude control prior to/ during 2nd stage depletion burn.

The consequence anticipated for these types of failures amounts to a failure to achieve proper orbit, and hence to mission failure, with either later or earlier re-entry for stages and spacecraft than is the case for a normal mission. Orbital collision and damage to assets in space or on the ground are not among the consequences and risks considered in Ref.1B.

Based on information available at this time (e.g. Refs.3,4), there is no direct evidence of any on-orbit collision damage to an active payload due to spent stages previously left in orbit (beyond the instance of the Japanese satellite, which collided with its own 3rd stage in 1979), and very low probabilities of such accidents. Secondary debris damage from past Delta upper stages has also not been claimed to date.

While the stages spiral in during orbital decay, they sweep a range of orbital altitudes and inclinations, below nominal, down to ground level. Most of the stages hardware burns- up during re-entry, with only selected high drag- low mass fragments (e.g. spherical liquid or pressurized gas bottles) surviving to ground impact, to be occasionally recovered. Decaying debris associated with any launch are normally numbered in the SPACECOM (previously NORAD) Catalog, and are routinely tracked by the Satellite Surveillance Center (SSC), which sends out decay notices starting at 60 days before estimated re-entry time, and TIP (Tracking and Impact Prediction) messages to the State Department and other agencies (see Ref.3).

Random re-entries from parking orbit can either be due to normal operation and decay of the 2nd stage, or to mission- critical failure modes, which could lead to retention of the 3rd stage and payload in parking orbit and to their premature re-entry. The latter scenario clearly entails higher risk to population and property on the ground (more debris, greater lethal area), but may have a lower probability, and hence not increase the risk level significantly.

Similarly, random re-entry from GTO can occur either from a nominal 3rd stage jettison, or from any malfunction leading to premature payload separation, or to no separation. Again, only the early (up to 1971) Aerospace reports done to fulfill re-entry safety SAMSO Regulations adress both the probabilities and consequences (casualty expectation) from these random re-entries, due to both normal and

accidental re-entry from parking and GTO orbits. SAMSO Form 4 (see Table in Ref.9) is no longer required for mission approval.

Unless a space accident involves a failure to separate the payload from the upper stage, or failure to achieve proper orbit (i.e. underperformance), or a faulty firing and separation sequence, the hazards to ground targets from premature re-entry of the 2nd and 3rd stage are probably the same, no matter when their re-entry takes place from a given orbit (although the time and place, hence the probability of land impact, and the country at risk, may be different, but this cannot be controlled at present).

The MDAC assumption in the analysis of Table 2, Ref. 1B, that the time of re-entry of stages and debris does not affect the risk level to population and property, appears reasonable: whether within a month, or many years, the uncontrolled re-entry risk per launch event is assumed to be the same. Table2 in Ref.1B, does not consider the population risk associated with on-orbit failures to be higher than for normal missions, even though the spacecraft re-enters in addition to the spent (or failed) stages. However, were the re-entry risk to be normalized not "per launch event", as is customary, but "per year", or "per life in orbit", then the risk due to near-term re-entry of a failed ELV plus the spacecraft, would probably exceed the risk associated with three separate uncontrolled re-entry events, spread over the 10^3-10^6 years time span to the eventual spacecraft re-entry from normal GEO missions. Admittedly, this view is debatable, given the differences between the " time integral" vs. a "delta function in time and space" approaches to re-entry risk estimation. At present, re-entry risk assessment is an area of active research and re-evaluation by the Transportation Systems Center (TSC) technical staff, in support of OCST licensing decisions.

The mission profile for the Delta 4925/ INSAT shows land overflight trajectories and IIP traces over Africa and Madagascar (Figs 1-6 and 1-7, ibid.), similar to previously approved and successfully completed missions. The Range Safety Flight Mechanics Destruct Analysis document submitted to the Range for approval, has been "updated" for the 4925 vehicle, and defines destruct action and/or vehicle break-up debris shapes, sizes and re-entry characteristics (excerpts were provided in Book 3 of the MDAC License Application). A Casualty Expectation estimate for land overflight of 3.6×10^{-7}, as well as a discussion of other public safety issues associated with the Delta/ INSAT launch, has been provided in Ref. 10.

Materials from MDAC and NASA on file at TSC list past Delta mission failures (through Delta 178 in 1986). These indicate that only five of the eight Delta 2nd and 3rd stage failures to date have led to premature re-entry of stages and spacecraft, and only one has involved land impact, but none has caused any reported damage on the ground. Only one of the Delta failures involving the 2nd stage has required destruct, in order to control population risk. The NASA discussion of historical failures spells out the consequences of some of the 2nd and 3rd stages on-orbit failures, none of which has led to known damage or injuries. Some of these consequences are generic, and therefore applicable to the current Delta orbital failure scenarios: In the case of Delta 1 and 86, the 2nd stage lost pointing control and the 3rd stage fired along the wrong direction, leading to payload re-entry. For Delta 24 and 71, the 3rd stage underperformed, and the spacecraft failed to achieve orbit and re-entered. The 3rd stage of Delta 33 failed to spin up sufficiently to stabilize, became unbalanced and re-entered with the payload. The Delta 100 and 130 on-orbit failures involved loss of pointing reference during SECO 2, and improper pointing, stabilization and orbital insertion of 3rd stage and payload,

which could have led to re-entry with land impact. It is possible that these types of failures will reccur, albeit with a lower probability, given the NASA "failure analyze and fix" approach to preventing the reccurrence of diagnosed mission failures.

3. ACCIDENT PROBABILITIES

In this section, the available probability estimates, by failure mode, for the main classes of accidents identified in Table 2, of the MDAC Supplemental License submittal (Ref.1B) are reviewed and evaluated. These probabilities can serve to rank the accidents according to their likelihood, so that the accident consequences can be appropriately weighted, in order to assess the associated risk levels. The seven generic on-orbit failure modes identified and evaluated by MDAC have individual probabilities ranging from .2 to 7x 10-5, but add up to an aggregate orbital failure probability of 1.7x10-4, or less than 1 in 5000. This is clearly an optimistic estimate, probably based on predicted component and subsytem reliabilities, though we found no justification for the probabilities given in the materials provided by MDAC. This low aggregate probability of 2 in 10,000 for an on-orbit failure involving a 2nd and/ or 3rd stage is not consistent with either the observed historical failure rate of 4.4% in the 2nd, or 3rd stages of the Delta rocket, nor with the figures given by MDAC in Table 1-5, Ref. 1A, as discussed below. However, since the Delta vehicle has been continually upgraded and reconfigured, only a few of these historical failures have actually occurred "on-orbit" and on the 2nd and 3rd stages hardware currently in use, and thus may not be directly applicable. In fact, Tables 1-1 through 1-5 in Ref.1A indicate that the 2nd stage Aerojet motor has flown only 14 times, with no failures, while the 3rd stage Star 48 B Morton Thiokol PAM-D has sucessfully performed in 13 Delta missions, all since 1982..

Given the Delta 4925 similarities to the flight tested 3925 series, the reliability and mission success predictions for Delta 4925 are based on the 3925 performance. Table 1-5 in Ref.1A compares the reliability predictions for the 3925 and the 4925 configurations (vs. few actual figures available) by stage, and by subsystem for each stage. It is apparent from the footnote to this Table that 13 of the 14 Delta 3925 missions were 3 stage missions similar to the proposed configuration. The identical 2nd stage hardware has successfully performed in 14 launches since 1982, 12 of which were from ESMC. Hence, only an upper limit on a 2nd stage failure probability can be estimated (P_f less than 7%) The 2nd stage unreliability (Q = 1-R) is inferred to be about 2.4% for the 2nd stage, and .2% for the 3rd stage, while the overall predicted failure rate for the 4925 vehicle is estimated to be about 2.6%. These predicted figures agree well with the historical failure rates for Delta 2nd stages (2.2%), but not with that observed for earlier 3rd stages (2.2%). Since no failures on the Star PAM-D have occured as yet, the predicted .2% figure has been accepted as a lower limit. Since the 3rd stage PAM (Star 48 B) has successfully performed in 13 previous missions, an upper limit may be set on its failure rate of less than 1 in 14 (or less than 7%). However, since spin-up and separation of the 3rd stage are commanded by the 2nd stage guidance system, it is likely that any 2nd stage failure inherently leads to a 3rd stage failure, and that this is the operationally limiting probability figure of interest here.

The typical approach to predicting future failure probabilities has been to use historical performance data, although MDAC has shown that operational reliability has improved steadily over time, to the present 93.6% cumulative. Of the 12 failures of Delta missions, on which we have obtained detailed information from MDAC and NASA, four have involved the 2nd stage, and four the 3rd stage, hence 2/3 of all failures(for an overall 4.4% probability, out of a 6.6% total, based on 12 failures

out of 182 missions) can be considered "on-orbit" failures. 1/3 of these failures required destruct action, only one of which involved a 2nd stage malfunction. Since corrective measures have largely removed the sources of past failures, or decreased their probability of recurrence, it may not be advisable to use past failure modes and probabilities as a predictor of future performance.

The ESMC statistics for Delta military space missions (obtained from Lou Ullian and reproduced in the RTI ESMC Baseline Assessment), give 5 failures in 79 Delta launches, corresponding to a reliability of 93.7% and a failure probability of 6.3%, or 1 in 15. Overall, based on analyzing the time of failure for 216 launches of ELVs (including Atlas/ Centaur and Titan III/34 D), 14 out of 16 (or 86%) occurred during the time interval 30 sec to orbital insertion. The overall reliability of FTS systems at ESMC, for over 2900 launches, is .999, or a 1 in 1000 failure rate observed for redundant sytems. ESMC assumes an overall probability of 6.8×10^{-2} for failures which occur between 30 sec and orbital status, requiring destruct command, in which case the prescribed destruct lines protect populated areas from debris. Also, a 6.8×10^{-5} probability is assumed at ESMC for a destruct system failure, which could affect a failed 2nd stage and the 3rd stage prior to separation..

This historical approach to failure rate prediction may not be directly applicable to the Delta 4925 configuration, since new flight hardware for the 2nd and 3rd stages was introduced in the interim. Not all earlier Delta 2nd stage failures can be considered technically "on-orbit failures" : in the absence of strap-on motors on the first stage for the less capable earlier Delta vehicles, the 2nd stage did not achieve orbit. Since Delta 44, it appears that 2nd stages were considered to be in orbit after burn. Given, however, that new modifications ("uprating") probably introduced new, and possibly as yet unforeseen failure modes, it may be realistic to assume that the gross mission failure rate will be close to that historically achieved. For example, the Delta 178 short circuit failure, which led to mission loss, was not predicted by the FMEA. Hence the 4.4% total probability for on -orbit (2nd stage + 3rd stage) failure could be used with reasonable confidence as a prudent estimate in setting insurance requirements for the orbital operations phase.

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1. A) MDAC License Application to OCST, Feb.16, 1988, Books 1-3;
B) MDAC Application Supplement re On-Orbit Risk Information, May 11, 1988.

2. "Hazard Analysis of Commercial Space Transportation", Draft, March 1, 1988.

3. Memo (4.22.1988) and Addendum (4.27.88) from A. Brecher to OCST.

4. "Artificial Space Debris" by N.L. Johnson and D.S. McKnight, Orbit Book Co, 1987.

5. "Convention on International Liability For Damage Caused by Space Objects-Analysis of Background Data", 1972 Senate Print 75-871

6. Letter from Peter Eaton of NASA to OCST (4.22.1988) and Attachments:
A) Delta 180 Orbital Safety Comm. Report, Aug.1986;
B) Delta 181 Orbital Safety Comm. Report, Dec. 1987.

7. A) Delta Range Safety Land Impact Probability Study", SM-43503, July 1963, Douglas Aircraft Co for NASA.
B) "Improved Delta Lethal Area Report", SM-48892, Oct.1965
C) "Improved Delta Range Safety Land Impact Probability Study for the Pioneer A Spacecraft Mission", SM-48995, Aug.1965.
D) "Delta Range Safety Land Impact Probability Study", SM-52341, Aug. 1968.

8. A) "Delta II Failure Mode and Effects Analysis", MDC H3324, July 1987 , for the USAF.
B) "Delta II Reliability and Maintainability Allocations, Assessment and Analysis Report", MDC H3058A, March,1987.

9. " Public Hazard of Second Stage Debris Re-entering the Atmosphere and the Re-entry Hazard Estimation for the Launch of the Martin Marietta Commercial Titan", Memo by David Knapton, TSC to OCST, May 13, 1988.

10. " Review and Analysis of INSAT 1D License Application", RTI, May, 1988 for DOT/OCST

Mr. NELSON. Good.

Before we get into our questions, I am told that this exhibit over here is very worthwhile for us to see, and some of it is delicate so that it can't be passed around, so why don't I invite the Members at this point an opportunity to check out some of this debris exhibit, and then we'll proceed with the questions.

Mr. MAHON. It, Mr. Chairman, has been prepared by Mr. Don Kessler, and I'd like to invite him to answer any questions that you may have on that. Don may be able to describe some of the pieces and go through it on that one.

[Members examine exhibits.]

Mr. NELSON. All right. That's a vote. It looks like it's a vote on the Journal, so we will recess and go vote and come right back.

[Recess.]

Mr. NELSON. Questions for the panel. Mr. Packard.

Mr. PACKARD. Thank you, Mr. Chairman.

Certainly this is a timely and, I think, a very important hearing, and members of this committee, in fact the entire space industry needs to become much more aware and aroused over the issue of space debris.

What we have seen here and all of the indications in the testimony are that the particles that we're dealing with are minuscule in size, perhaps very devastating in its effect, but are we going to experience, or are there experiences with large particles out there in space, or are we looking in our remedies and in our solutions, are we only looking at very small particles? Do we see entire parts, for example, of equipment out there?

Mr. MAHON. I'd like to try to record, the larger particles generally occur at higher altitudes, where you have the benefit of the geometric expansion of space, and there are less of them, so that the probabilities of the impact occurring are smaller. They're there, but it's not a problem at this stage.

Mr. PACKARD. Do we have any evidence that any of our satellites that spend years up in space have been damaged by—even to the point of impairing function? Do any of our satellites have evidence of any damage from impact?

Mr. MAHON. I said in my testimony that we have no known impacts from debris, but I guess what I should have said is that we have no confirmation of impacts on it. There have been satellites. The Kosmos 1275, a Russian ASAT, and our own PAGEOS balloon, which are broken up and probably as a result of a collision. They were in an area of high debris, and the break-up did occur. It was not a scheduled event, and we have no way of confirming that it was actual debris that caused that to occur.

Mr. PACKARD. What are possible solutions? What do you see as solving the problem? We're going to be adding to debris in space at almost geometric numbers in the future. What is being considered as possible solutions?

Mr. MAHON. I think one of the ways we can start is education, education of the system space designers for the need for litter-free systems, to be able to design systems which don't add to the contribution of it.

We can take technology as the second step and have advanced ground-based and space-based detection systems so that we know where the space—where it is.

Comprehensive models of the environment so that we can maybe predict them from expanding or growing on that one.

Design of operation of debris monitoring systems, like we're trying to do under the radar.

If then we move to space vehicle design, if we design litter-free systems that actually don't contribute to it and try space system disposal by retrieval—can we pick up something the way the shuttle picked up those two spacecraft which failed, the Westar and the Palapa mission—can we put them into a little bit more velocity and drive them into escape, can we drive them into re-entry conditions, or can we put additional shielding on them the way that the space station is preparing to answer the question now by having an additional gap between the pressure vessel, and they will have an additional bumper there to take the brunt of the debris that it would required, just like that one did.

Mr. PACKARD. Similar to that.

Mr. MAHON. That's the classic example on that one.

Mr. PACKARD. Are there ways of redirecting the debris to force it into entry?

Mr. MAHON. Yes, sir, and we can make designs that decentralize or have experiments performed at altitudes, as we did with the DOD, at low altitudes enough so that the debris will fall in.

One of the questions that the chairman asked earlier was, does this debris re-enter on that one? Historically, there have been 18,000 known objects that have been catalogued, and today there are in orbit about 7,000 of them; 11,000 of them have fallen in; they have been burned up and have decreased on that one. So there is a natural rain-down of these objects on that one.

Now one can assume that if 18,000 were there and there's only 7,000 now of the known catalogued, the ones that we can actually see either radar or optically, then the debris problem would have the same fallout on it, and there is a decreasing set on that one.

The other thing is—that may be of some help is the natural phenomenon now where we're going into the solar cycle, and as the solar cycle increases the atmosphere heats and rises. The rise of the atmosphere then gives greater drag to those objects that are in orbit, and then they start to fall out of orbit and decrease, so that we would see a natural contribution occurring. That cycle is starting to occur now and will probably be peaking somewhere in the '90, '91, or '92 time frame, and that will contribute to a reduction on that one.

But that doesn't say we should rely on it. We should take these design steps that I mentioned earlier on that one. I think that we should limit explosions to low altitudes so that they can fall in on that way.

Planning our launch trajectories for early re-entries. When we inject into the geosynchronous orbit, we inject at a low parking orbit at one end, and it rises to the other end, so that we can do that. If we then have a highly elliptical orbit as it re-enters the atmosphere, it tends to slow down each time it re-enters and then fi-

nally does a re-entry to burn, and you don't have the stage in orbit for that one.

So there are steps, and I think that we have been practicing many of these steps. I think we have to do it more positively in that period of time.

Mr. PACKARD. What are some of the—and this is my last question, Mr. Chairman—what are some of the impediments to international cooperation with the Soviet and the Free World space programs? Are there impediments to prevent us from working together on solving the debris issue?

Mr. MAHON. I don't know that they're specifically impediments or not. I think that there's a general awakening to the same problem that we are—as we are. The other elements are starting to do it. There was—as I mentioned earlier, we do have the experience where ESA—working with ESA to cut down the debris from their stages on that one. They don't want them in orbit any more than we do, and the Russians are expressing interest through the international fields now. It has been initiated. We don't know yet to what extent that they're going to do it, but I think that they're beginning to feel the problem rise too.

Mr. PACKARD. Some of the solutions that we have sought for and are looking at in terms of man-made debris, would they be applicable to natural debris, some of them?

Mr. MAHON. Yes, sir, they would. The greater frequency of the collisions is the thing that we're trying to reduce, which prevents additional growth in the debris situation.

Mr. PACKARD. Thank you, Mr. Chairman.

Mr. NELSON. Mr. Brown.

Mr. BROWN. Thank you, Mr. Chairman.

Possibly Mr. Kunsberg would be the best person to answer this question, but do you have—have you made any effort to determine the relative proportions of debris now in space resulting from Soviet anti-satellite tests which took place over a number of years and U.S. anti-satellite tests which were considerably less versus other sources, basically civilian launches or accidents, and one thing and another?

Mr. KUNSBERG. Yes, sir, we do have some statistics on that. There has been, as you know, only one U.S. anti-satellite test, and the statistics we do have—that was the miniature homing vehicle which impacted with the Solwind satellite in September 1985, and we catalogued 287 pieces of debris from that event, approximately half of which have de-orbited at this time.

Mr. BROWN. Those were materials that you could see, in other words, more than 10 centimeters in size.

Mr. KUNSBERG. That's correct.

Mr. BROWN. You have no way of estimating the amount of sub-10-centimeter debris.

Mr. KUNSBERG. That's correct, sir.

Mr. BROWN. Okay.

Mr. KUNSBERG. With respect to the Soviet anti-satellite test, as you know, in effect, the vehicle destroys its target by creating debris. In effect, it explodes a hand grenade in the vicinity, or hand-grenade type device that creates very many fragments.

Mr. BROWN. Correct.

Mr. KUNSBERG. I do not believe we have specifically catalogued the number of pieces of debris caused by Soviet ASAT tests.

But the issue of ASAT testing really should not be, I think, a cause of particular concern with respect to debris, simply because there are—at least from our perspective, there are very definite things that can be done and are being done, should there be such a test, to minimize or avoid debris. It's not simply a problem with respect to ASAT tests or anything else. Other activities, such as the SDI Delta 181, were conducted in such a way so that, because the event was in an extremely low orbit, the lowest possible orbit within the parameters of the experiment, all of the debris eventually de-orbited, or at least all that we can detect.

So, in addition, much of the other testing—testing of that type for various purposes can be done with what we call an instrumented test vehicle, which is, in effect, a balloon that inflates with various instruments on it and so on, and those tests can be—many measurements can be taken without destroying the test vehicle itself, and it, again, can be done in low altitudes so that there is eventual de-orbiting.

But on the larger issue, the statistics we have shown a rough equivalence in terms of the large pieces of debris that are currently on orbit. The U.S. and Soviet contributions are roughly equivalent as of this time, but what we see is a definite trend. In recent years, of course, the amount of debris resulting from Soviet space activities has been increasing and is certainly—

Mr. BROWN. What do you attribute that to, since they stopped ASAT testing about six or eight years ago?

Mr. KUNSBERG. Well, as I say, ASAT testing is not the primary concern with the debris problem at this point. The primary causes have to do with the natural process of launching—second stages and so forth, the other large objects that are left, also natural explosions and collisions. Many of the events which have caused the greatest amount of debris have to do with, for example, second stages that exploded because cryogenic fuels were left on board, and some of the other events that Mr. Mahon has mentioned were just spontaneous explosions or explosions caused by debris or other—

Mr. BROWN. Well, the purpose of my question is to try and quantify the relative causes of these in as reasonable a way as I can. I think the Defense Department is to be commended for the efforts they've taken to reduce the amount of debris from their planned activities. The instrumented balloons as anti-satellite targets are an excellent example as compared with, say, destroying an existing solid satellite which would produce far more. But we need to understand the relative dimensions of this. Even an instrumented balloon type target is going to release, to say the least, the instruments and pieces of the balloon skin and other things which, regardless of whether they're made out of rubber or anything else, have just as much impact when they hit something, I think. Is that correct?

Mr. KUNSBERG. Well, it depends. Some tests can be conducted nondestructively. But for example, if there's an impact with a kinetic energy device, that would be a correct statement, sir.

Mr. BROWN. Well, my next question had to do with whether or not the Defense Department has made any estimate of the amount of debris that would be produced by the explosive destruction of, say, a dozen Soviet satellites, using a miniature homing vehicle.

Mr. KUNSBERG. The answer is no, we have not made such—

Mr. BROWN. You haven't even thought about it? And I could ask the same thing about—

Mr. KUNSBERG. It's not something that we contemplate.

Mr. BROWN. The same amount of debris would be produced by a Soviet anti-satellite explosively impacting a dozen U.S. satellites, maybe more because ours are bigger.

Mr. KUNSBERG. The answer is, we have not made such calculations. It's not a contingency that we contemplate in terms of anything short of an actual armed conflict. In those situations—

Mr. BROWN. Well, can we say that it would be at least 12 times as much as the debris produced by the one test that you conducted against the satellite and probably, since it would be in higher orbit, it would remain up there longer?

Mr. KUNSBERG. It simply would depend on the kinds of satellites and the nature of the impact, and it's simply a calculation that we haven't undertaken simply because it's not anything that's being contemplated or—and I might add that the only contingency where anything like that would ever occur would, of course, be in a state of conflict in which debris would be a secondary consideration.

Mr. BROWN. But of the scenarios I've seen for the use of American ASAT's do not include all-out nuclear war. They are kind of surgical strikes at the Soviet RORSAT's and things like that which will just produce debris but not precipitate a nuclear war, and I'm concerned about what the future of space would be in the event that something like this happened. You have made no studies of that. Would you like to make some?

Mr. KUNSBERG. I think the dimensions of the problem of space debris is something that will be part of this interagency study that we're conducting now. I know that the creation of space debris in a state of conflict is something that has been considered. I can't speak directly as to the degree to which the long-term effects of that have been considered.

The primary point is that we would never reach that point of actually—I mean should we reach a state where there is actual employment of ASAT weapons, that would be a very extreme and serious national emergency, and it would be a situation where I think the considerations of space debris would be secondary.

Mr. BROWN. Well, you're quite right, in the event of nuclear war space debris would be secondary, but I've been trying to get the Defense Department to enunciate policy with regard to use of space weapons, and I haven't gotten a very good answer yet, and one of the things that I haven't got is the extent of space debris that would be produced in a nonescalatory nuclear war, at least, scenario, and I think you ought to think about it.

Secondly, if the Defense Department is really serious about proposing an extensive SDI deployment, either the so-called initial system or a more elaborate system later, which would be the subject of ASAT attacks, I'm wondering what the status of that system would be in terms of its reliability in an environment filled with

debris. I wonder if that subject has been subjected to the analysis that has been made in an effort to justify some of these systems.

Mr. KUNSBERG. Sir, I do know that the people who are studying the SDI battle management and discrimination problems take full account of all of these contingencies. Again, I can't speak to the results. It's something that's ongoing, but it certainly is something which they are cognizant of.

Mr. BROWN. Do you think it's a factor that's of sufficient importance to be considered?

Mr. KUNSBERG. Yes, sir, and I'm quite certain they are considering it.

Mr. BROWN. Okay.

Mr. NELSON. Mr. Smith.

Mr. SMITH. Thank you, Mr. Chairman.

I must confess, I'm amazed at the magnitude of the problem. In the four years that I've served on this committee, this is really the first time, that I can recall anyway, any witness addressing this issue.

In response to a question that Mr. Packard asked earlier about redirecting the debris back—redirecting it so that it could be burned then out of orbit, could you be more specific, if you can be at this point, on how you would do that, how you would accomplish that?

It seems to me—one editorial point—it seems to me that, based on what I've read and what you've said, you either have to redirect it out and burn it up or avoid putting it up there, or avoid the debris with the vehicle—with your shuttle or whatever the vehicle is up there. It just seems to me that out of those three we're not ready to say yet that we can avoid putting it up there unless we just don't go up.

So it just seems to me that, out of those three options right now, that redirecting it into burning it and re-entering is the way to go. Could you get a little technical about how you would accomplish that?

Mr. MAHON. Yes, Mr. Smith. At least, I'll try.

Let's take a spacecraft which is going into orbit as a weather satellite in a polar orbit. The second stage which accelerates or provides the velocity for that spacecraft to get into orbit has the same velocity as the spacecraft. So it stays right there along with it.

Normally what we do in a case like that is have the rocket motor, the spent rocket body, do a collision avoidance maneuver and either vent some of the control gases or a small burn of its control system to separate the distance between it and the spacecraft so that you don't collide with it, and that stage then spins the same orbit as the spacecraft could be.

Now how could you prevent that? One way could be to provide it with enough intelligence—and it runs into significant costs to do that—to be able to measure what it's body is. The way that stage is built and constructed now is to live 60 minutes roughly—maybe an hour, maybe two hours at the most—and then it's spent.

But if you qualified it for a longer life and had batteries or power supplies on it that controlled its stabilization and had enough gas to control it during that period of time and then an auxiliary motor to burn it and a communications system so that you knew

where it was when you were tracking it and were able to direct its burn—you see how complex it's getting? Each step provides a little bit more information on it—then you could direct that burn to occur, let's say, over the Indian Ocean, over the Pacific Ocean, over the Atlantic Ocean, or some uninhabitable place during that period of time. But it involves design of areas that—it cuts down on your payload weight.

One of the earlier estimates, 30 or 40 percent, is not an un—then the cost of tracking it, the cost of controlling it. We may have to go to that eventually, but right now it's not necessary we do that.

One of the ways that we have been able to do it is by venting the gases in that spent stage, and that causes the explosion not to occur because the hyperdrolic propellants are not there at the time when the explosion would occur.

Another one would be to even put it on the spacecraft and have a small method of propellant on board the spacecraft which would—after it had served its useful lifetime.

Suppose you had a communications satellite and the design of it were such that it would operate seven years and then at that point start to deteriorate. As it began failing, you could fire it, provide it an additional nudge, and give it enough velocity to escape so that it would escape the Earth's environment, and then you wouldn't have the debris problem. Of course, you would be contaminating a bigger ocean, but at least you'd be relieving our problem.

Mr. SMITH. In some of our background information there were references to this as well as better shielding on the shuttle, and an afterthought or footnote to that was cost, and I would just—I'm far from being an expert on this, but I would just urge a word of caution. Let's not make the same mistake in space that we have made here on earth with the debris and pollution and so forth which have caused us problems because we didn't take the proper precautions earlier, and I think we have the opportunity to do that now.

We're talking now about moving commercially into space as well as governmentally around the world, and I think whatever cost it is, if we're going to go in space, we ought to proceed with the means to cut down and reduce and eliminate, frankly, the man-made debris.

I'm looking at statistics that say here scientists estimate that a Shuttle has a 50 percent chance of being struck in a 17-year lifetime and destroyed, a 1 percent chance of actually being destroyed.

I would like to ask perhaps any one of the four of you, if somebody said to you that the shuttle had a 50 percent chance of blowing up when it left the Earth, would we send it up? and the answer is, obviously, we would not. So now what we're saying is, it has a 50 percent chance of being hit. Now what about that hit?

You can saying being destroyed totally; that shuttle could be hit without being destroyed and still destroy life, and I'd like to hone in a little bit on just between that 1 percent and that 50 percent where is there a risk of life here. I mean I think we have some very, very serious problems, and I'd like to see somebody address that.

There's a big latitude there between that thing being hit, just being hit, no damage, over a 50-year period, or 17-year period—excuse me—or being hit and destroying life, or destroying—the

shuttle is one thing, destroying life is another. I mean it may not destroy the shuttle, it may destroy life, and I'd like to hear some comment on that, if you can, from anyone.

Mr. MAHON. Well, I guess I'll take a crack at that one, too.

Mr. SMITH. You're getting stuck with them all, aren't you?

Mr. MAHON. Yes.

The 17-year life is an operating life, and when the—basically, when the shuttle operates 7 days during this period of time on one mission, it takes many, many missions before the 17-year lifetime comes out, and I'm not that much of a mathematician—

Mr. SMITH. I said shuttle; I meant to say space station or telescope or some other orbiting—a misstatement.

Mr. MAHON. Yes. But from the space station standpoint, we do have a method under way. In addition to those, they have end caps on it, for example, which, as the thing flies facing its axis along its orbit, there are end caps which are buffers for orbital debris, in effect, to have that platform the way that one is separated, and they have tests done on the relative thickness of the material and the spacing that is required between the two or more plates that are required to protect the space station.

Mr. SMITH. In a broader scope, I just want to get a reaction. It seems to me, Mr. Chairman, that what we're saying is, it's unacceptable risk to put the shuttle or any manned—any object that's carrying man into space if there is this kind of risk involved, yet we are not making that same condition once they're up there in terms of being hit by debris. I mean I see an inconsistency here in policy, and I want somebody to address it. Nobody has. I mean death is death, and an accident is an accident, and I hear us saying, in one case, when we send it up it's unacceptable risk and yet, after we're up there, it's acceptable risk. I mean that's what we're saying.

Mr. MAHON. I just don't feel enough to answer that one. However, we may have a person here who can answer that. Mr. Don Kessler from Johnson has done many of the studies along this regard, and with your permission, sir, I'd like to—

Mr. NELSON. Mr. Kessler, please.

Mr. KESSLER. Would you repeat the question, so I know what I'm answering?

Mr. SMITH. Essentially what I'm saying is that if the—in the firing of a rocket which puts a shuttle or some object carrying man in space, we are saying that if there is a 50 percent risk of damage to that—to that vehicle that takes man into space, we're not going to send it up, yet there is—at least if it's not 50 percent, certainly a high risk, or at least a known risk, of that object being hit, perhaps crippled, perhaps causing the death of an astronaut in space, and yet we are not addressing that.

We are not saying, for example, that in September when the shuttle flies that we're concerned about that shuttle hitting anything in space, but we are concerned if there's some damage to the vehicle that would put them up there that might risk their life, as you well know by the extent of the $2.5 billion or so that we've done in the redesign.

I mean I see an inconsistency in policy here, and I want somebody to address whether or not it is an inconsistent policy and, if it isn't, then why isn't it?

Mr. KESSLER. I'm not sure that it is inconsistent because of the numbers that you've quoted. There's not a 50 percent probability of losing a shuttle as a result of orbital debris.

Mr. SMITH. I know that, but what is the percent of crippling that shuttle causing death to the inhabitants of it?

Mr. KESSLER. There are some—let's see. There are some numbers in the testimony that are something like one chance—you have to fly—be about 72 years in space in order to receive a crippling impact, or 71 years, based on our current understanding of the environment, and since the operational life of a shuttle is about 100 flights and each mission is about a week long, that would mean the equivalent, roughly, of 2 years in space. So that would roughly be about one chance in 30, based on our current understanding of the environment, which is based on an extrapolation.

Mr. SMITH. One chance in 30?

Mr. KESSLER. Thirty, during the operational lifetime of a vehicle.

Mr. SMITH. And the next question is, if we were told that one chance in 30 the shuttle would blow up upon ignition at Cape Canaveral, would we send it up?

Mr. KESSLER. But this would be 100 launches, though. It would be one chance in 300.

Mr. SMITH. Okay.

Mr. KESSLER. Per launch then, and I don't know what the current—

Mr. SMITH. Okay. I just have one final question, Mr. Chairman.

What is the danger of the debris to Earth inhabitants? I know we had one of the Soviet stations that burned up over—was it Canada? Any percentages out there as we increase—obviously, as we increase the amount of debris, obviously the larger pieces are in more danger of not burning up by the time they get back to Earth. I mean have we been able to measure any of that to inhabitants of Earth?

Mr. KESSLER. There have been studies to look at the debris hazard from re-entry, and all the conclusions are that you're more likely to be hit by a natural object than an artificial object from re-entry, and consequently that's not been deemed a significant hazard, but of course it's one that you would want to be concerned about in something big like Skylab where all of that probability occurs at once, and it's worth considering but it's not a major consideration.

Mr. SMITH. But as I understand it, these objects are increasing exponentially as they're hitting each other, but you're saying the smaller they are the more apt they are to burn up, so maybe that's an advantage.

Mr. KESSLER. Right. It's only the large stuff that you worry about for re-entry, though. Exponential increase in the small stuff is really not a concern to re-entry.

Mr. MAHON. I seem to remember a study completed several years ago where they were trying to survey whether anybody had actually been hit by any meteorites or micro-meteorites, and there is no

known history of impacts from that. There are some nearby, but no people have ever been hit by natural debris.

Mr. STADD. Congressman Smith, if I may respond from DOT's perspective, one of the findings from our hazards analysis—and I emphasize that this analysis is basically what I'd call a base line descriptive so that the Department can at least get an empirical sense of what the probabilities are—is that what we have is a dynamic situation. If we did absolutely nothing, we would essentially have a situation that would approach crisis proportions by about the year 2000.

Secondly, we do think that in 1988, as we are approaching this situation we think systematically, that there are steps that we can take to mitigate the problem. At this point, you're dealing with fairly low exposure probabilities. But, as I say, it is a dynamic situation.

Mr. SMITH. Excuse me; I'm sorry to take so much time.

My concern is, I mean we are all so anxious and looking forward, obviously, to getting into space, and, as the chairman knows, I'm certainly one of those who support doing that. I just don't want to see us—somebody coming back to this committee in the year 2000—I don't know whether we'll be here then or not, Mr. Chairman; I hope not—and saying, "Look, we can't fly because we don't have an international agreement; there are too many things up there, and it's not safe."

I guess that's why I've been kind of harsh on the questions. I just am so excited about the future of space and what it can do that I think we ought to be able to lick this problem, and I want to see us do it before we have to stop flying and sit back for a number of years and wait for everything to burn up and then go back up again. Hopefully, we can resolve it without that. That's why I was a little hard on the questions, but thank you.

Thank you, Mr. Chairman.

Mr. NELSON. Thank you, Mr. Smith.

Let's take Mr. Stadd's comment. Do the rest of you panel members generally agree with what he said?

Mr. KUNSBERG. I would disagree with his characterization of the crisis. I think our long term projections are clearly that it is becoming a more significant concern, but I think all of the statistics are that even by that time or significantly later there will be a relatively low probability of impact with spacecraft. Now that would change if you're talking about very large space structures.

So it's much more of a concern for something of the dimensions of the space station than it would be for most of our other satellites and so on, and there's a very high leveraging effect in terms of the mathematics when you increase to that degree the size of the structure. But I think it's something very serious, and we're all intent on addressing the problem. I would not call it a crisis.

Mr. NELSON. Well, we—as a matter of policy we could do nothing; we could do what the administration's suggestion is, which is, basically, do the best we can and try to coordinate this with other nations; or we could try to get a policy with other nations basically saying no increase in space debris, that zero growth, if you will, so that no additional debris goes up that does not decay in orbit.

Now I'd like to hear each of you comment on that kind of policy, whether or not it's feasible.

Mr. Mahon.

Mr. MAHON. Without being disrespectful, I think that's the kind of a statement that says where the admiral on a carrier says, "There will be no wheels-up landings on my carrier." We can't control it on that way. I think that we have no control over the collisions of the existing material that is there. I think that an admirable goal and a reliable goal would be to drive it towards zero, but ever getting to zero, the cost would be—you just couldn't control it from that standpoint.

Mr. KUNSBERG. Sir, I think, of course, we do need a policy on this and an international policy, and there are very positive things that can be done. I think the goal should not be towards some absolute level of debris but towards reaching agreement on those positive measures we can take that will significantly reduce the problem.

For example, the idea of venting fuel from second stages so they don't explode. We do have statistics that those kinds of explosions have dramatically increased the amount of debris in orbit, and so by a relatively simple and feasible measure, if adopted worldwide, we could make a significant impact on the problem, and I think it's those kinds of steps we should be looking toward.

Of course, the first phase of that should be, within our own Government, formulating a sound policy. Therefore, when we enter the international arena we will have a well thought out plan and set of recommendations to make.

Mr. MICHAUD. Mr. Chairman, while we don't have an adopted policy on this point yet, I'd like to suggest that one possible starting point for an international agreement would be to get other nations and operators to observe the same principle that we've enunciated in our space policy, which is basically to minimize the creation of space debris; try not to make the problem any worse unless you have to. I'm not sure it's realistic to go to a zero growth policy because it might be a major inhibition on space operations, some of which are essential.

But, as Phil Kunsberg has suggested, there are things that we already know we can do to reduce the amount of debris we create in those operations. I suggest a starting point is to get other nations to agree with us on the dimensions of the problem, the statistics of it, if you will, and, second, to move them in the direction of adopting a principle of minimizing the creation of space debris.

Mr. STADD. Mr. Chairman, in terms of the earlier point about crisis, I think I say that in the context that we have more and more actors getting involved in the space arena, and we have a problem which Dr. Kessler spent many years characterizing for us, that is, in the Government, that indicates we have an exponentially growing problem.

I think that the panelists have so far indicated some of the proactive steps that clearly have to, I think, be taken. From the standpoint of our particular constituency, the commercial launch industry, I want to make it very clear that the applicants have been conforming to the traditional Government practices, and McDonnell-Douglas is in one example, in fact, employing the vent-

ing policy that NASA instituted back in '82 and have every interest in proceeding with that.

Secondly, I might add, in the commercial satellite industry, we've been talking primarily about the launch side; on the spacecraft side, Intelsat-Comsat have taken the lead in ensuring that they have sufficient residual fuel to assure that their spacecraft can be permanently placed in orbit so that it doesn't de-orbit and then pose any sort of threat; and NOAA, as part of the Commerce Department, has been instituting a similar management orbital practice for several years.

Those types of conditions clearly ought to be continued to be implemented. I would re-emphasize what Michael just said. I think that we should do everything we can to assure that the international community is conforming to these practices, because if we look at the pie chart, as Phil also pointed out, the Soviet Union takes up a fairly disproportionate share in terms of this debris problem.

Mr. PACKARD. Mr. Chairman, would you be willing to yield for just a moment on the zero option?

Mr. NELSON. Mr. Packard.

Mr. PACKARD. The zero growth option.

Isn't it difficult to even know what a zero growth policy would involve when we don't know or we don't have measuring techniques—I don't presume we have measuring techniques—to determine how much of those particles out there are coming out by natural consequences and burning up and disappearing? We don't know how much we're adding out there on a permanent basis and how much is being taken care of by means that we have no measurement of. Is that true? I don't know that you can determine what a zero growth policy would be when we have no measuring devices to determine what's out there and how long it's there and what's being destroyed by natural means.

Mr. NELSON. Mr. Michaud, it is generally recognized here on the committee that I feel very strongly about the question of export of our satellites to foreign launchers, non-Western foreign launchers, as a matter of hurting the technology of this country and our infant commercial launching capability.

Now aside from that question, should it be a policy of the U.S. Government, particularly the State Department, that one of the major concerns that they would consider before granting an export license on a satellite to be launched on a foreign launcher, that that foreign launcher should be a signatory to the Outer Space Treaty, which indeed would cover some of the subject matter that we're discussing today?

Mr. MICHAUD. Mr. Chairman, as you know, the license application would be granted either by the Department of State under the Munitions Control regulations or the Department of Commerce under Commerce regulations. In the case of the Department of State, the provision that you have suggested is not part of the licensing system at this time. To my knowledge, there is no proposal within the administration that it should be included in the licensing system.

Mr. NELSON. Well, I might suggest that it should.

Mr. MICHAUD. I hear you, Mr. Chairman.

Mr. NELSON. If we're going to take seriously the subject that we're discussing today, then that certainly ought to be one of the criteria that you would look at.

Now I happen to think that we ought to take seriously the subject of launching on foreign launchers for other reasons before we ever get to the question of space debris and the Outer Space Treaty, but that's another little wrinkle, and we're going to continue to ask those questions.

Mr. PACKARD. Before you close, Mr. Chairman, may I ask one additional question?

Mr. NELSON. Mr. Packard.

Mr. PACKARD. Mr. Stadd, you used the term "crisis could be reached by the turn of the century" simply if we don't address the debris problem under current programmed space launches and space programs around the world, and I don't know that that's the correct term either.

If, in the event, world events moved to where not only would SDI be functional and war did involve space at some point in the future and SDI was able, on both sides of such a war, to destroy in space and explode in space oncoming missiles, what would be the effect then of debris, and would that become then a major concern with the amount of debris injected into space? Would that become of concern to any future civilian space programs that might follow such war activities? Any thoughts to that by the Defense Department?

Mr. KUNSBERG. Sir, respectfully, I would say that should the situation that you describe come to pass, we would be far more concerned with stopping Soviet ballistic missiles from landing on the United States—

Mr. PACKARD. No question about that. War certainly does pollute the Earth, and it could very well pollute the heavens.

Mr. KUNSBERG. I frankly think we would not be, in that situation, concerned about space debris. We would welcome the explosion of those warheads in space rather than on Earth.

Mr. PACKARD. Thank you, Mr. Chairman.

Mr. NELSON. Any questions from staff?

Okay. Gentlemen, we thank you. We want to call up our second panel. Thank you very much.

Mr. Hosenball and Mr. Johnson, as you know, what I'd like you to do is share with us a summary of your comments. We will enter your testimony in the record. We have had a fairly good airing of this issue and are looking forward to your perspective and comment.

Mr. Hosenball.

STATEMENTS OF NEIL HOSENBALL, DAVIS, GRAHAM, AND STUBBS, WASHINGTON, D.C.; AND NICHOLAS JOHNSON, TELEDYNE BROWN ENGINEERING CORPORATION, COLORADO SPRINGS, COLORADO

Mr. HOSENBALL. Thank you, Mr. Chairman. It's a pleasure to be here again after a rather long absence. What I would like to address considering the limitation of time that we have is just some key points.

What are the international obligations that launching states have with respect to orbital debris? There were two treaties that do affect the issue. The Outer Space Treaty is key to the issue of consultations. The Outer Space Treaty does require that states that consider some other state's activities would interfere to request consultations, and so there is a way for state parties to the treaty to call together other states to discuss the question of how to solve or at least to reduce the problem of orbital debris.

It is also quite clear that states are responsible for even the activities of their nongovernmental entities, and therefore Ariane and our own commercial launch providers would be subject to direction by the state responsible.

The other treaty basically is a liability convention. Under the liability convention, the U.S., as well as other states that are carrying on space activities, particularly those states that have a space station or shuttles or large satellites in Earth orbit, would be absolutely liable if for example, a piece of orbital debris was to so severely damage a large space object or a satellite, shuttle, or space station, cause it to re-enter and cause damage here on Earth.

We have heard today that many of these pieces are so small that they can't even be identified. In the normal situation, if you could identify who was the initiator of that orbital debris, then both states would be absolutely liable, but they would share the damages based on fault. The same would be true if there was no damage on Earth and there was a collision between two space objects. The party at fault would pay the damage.

So we have the two treaties.

The second question then I think is important to address is, how should we go about with these consultations? Now we do have at the U.N. a U.N. Committee on the Peaceful Uses of Outer Space. It was established as an ad hoc committee exactly 30 years ago this coming October. It has been a standing committee for over 29 years, and it has negotiated principles which don't have the force and effect of a treaty, but they also have negotiated five treaties during their life.

There is an Outer Space Division with a permanent staff including a space expert and the committee has a scientific and technical subcommittee as well as a legal subcommittee that does the actual work and reports to the full committee.

They have conducted studies in many areas. How do you decide the line between air space and outer space, remote sensing, nuclear power sources in space. So they do have the capability to initiate at least discussions on this particular problem.

The only concern I have is, if we're talking about this becoming a crisis in the year 2000, I'm not sure working through the U.N. and the committee will solve the problem in 10 years, and so I would suggest instead that we do invoke the consultation provisions, bring together the interested parties, the Soviet Union, certainly who is a major contributor, ESA, Arianespace, the U.S. and its commercial providers, China, India, and all the other countries that now have the capability to generate, if you will, orbital debris in space.

The question was asked, are there any problems that might arise during these consultations? I think cost is a problem. Will the

newly entering space powers, if you will, be willing to spend the cost to redesign the launch vehicles that they have just recently started to manufacture and design? I think it is important, however, since it is a threat to life, that cost considerations not be a consideration in deciding what is to be done.

That finishes my very short statement, Mr. Chairman. Thank you again for inviting me.

[The prepared statement of Mr. Hosenball follows:]

STATEMENT OF S. NEIL HOSENBALL
BEFORE THE
SUBCOMMITTEE ON SPACE, SCIENCE AND APPLICATIONS
OF THE U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

Mr. Chairman and members of the Subcommittee, it is a privilege to appear before this Subcommittee once again after a long absence. I have provided the Committee with a short biographical sketch and therefore merely wish to state that I am currently a partner in the Washington office of Denver, Colorado's Davis, Graham & Stubbs. Prior to joining the law firm, I spent a year at the University of Colorado in Boulder as the founding Director of a Center for Space Law and Policy. Prior to that, in a career spanning approximately 25 years, I held various legal positions in NASA, culminating in my serving as NASA's General Counsel for the years 1975-1985. While at NASA, from 1969 to 1979 I was a delegate or the head of the U.S. delegation to the United Nations Committee on the Peaceful Uses of Outer Space and, in particular, its Legal Subcommittee. I have also taught space law at George Washington University School of Law and at the University of Colorado Law School.

I appear before you to testify, and hopefully inform the Committee, about the international and legal considerations arising out of the orbital debris hazard that exists in low earth orbit. While this hazard has existed for quite some time, the amount of orbital debris in low Earth orbit has significantly increased and will continue to increase as more spacecraft are launched by expendable launch vehicles. The increasing amount of orbital debris presents a threat not only to spacecraft operating in low Earth orbit, but to men and women aboard the space shuttle, the Soviet Mir Space Station and to the international space station being developed by the United States and its international partners.

The question you have asked me to address is what are the relevant and current obligations of launching States under the existing space treaties that have entered into force. The number of launching States has increased dramatically in recent years and other States have joined what in the early days of space exploration and application was a rather exclusive club. In the early days, only the United States and the USSR had the capability to launch spacecraft from the Earth into space. Today, Arianespace is a major provider of commercial launch services and the Peoples Republic of China, Japan, India and others, either are launching spacecraft, have the capability or are developing the capability to launch spacecraft into space. What would have been bilateral negotiations between the US and

the USSR in the early days of space activities, now requires multi-lateral consultations and negotiations between and among all launching States to address problems and issues associated with orbital debris.

What are the current and relevant obligations of those launching States under existing treaties which they have signed and ratified? There are two treaties that are relevant to the orbital debris hazard problem, The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, generally referred to as the 1967 Outer Space Principles Treaty and the Convention on International Liability for Damage Caused by Space Objects, commonly referred to as the 1972 Liability Convention.

Under Article VI of the Outer Space Treaty, States parties to the treaty bear international responsibility for national activities in outer space, whether such activities are carried out by government agencies or by non-governmental entities. The activities of non-governmental entities in outer space requires authorization and continuing supervision by the appropriate state party to the treaties. States parties to the treaty are responsible for assuring that national activities, whether carried out by the government or by non-governmental entities, are in conformity with the provisions of the '67 Treaty.

Article IX of the '67 Treaty, requires that state parties to the treaty in the exploration and use of outer space be guided by the principle of cooperation and mutual assistance. They shall conduct all their activities in outer space with due regard to the corresponding interests of all other state parties to the treaty. Article IX further provides that if a state party to the treaty which has reason to believe that an activity or experiment planned by another state party in outer space would cause potentially harmful interference with activities in the peaceful exploration and use of outer space it may request consultation concerning the activity or experiment. Further, if a state party to a treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space would cause potential harmful interference with activities of other state parties, such state party shall undertake appropriate international consultations before proceeding with any such activity or experiment.

It is my view that if the United States has determined that its launching activities and those of other States cause

potential harmful interference in the exploration and use of outer space, it has a duty to enter into consultations with other States carrying out space activities and similarly if any other state believes that U.S. originated orbital debris could cause potential harmful interference with activities in the exploration and use of outer space, it may request consultation concerning the issue.

In addition to the provisions requiring States to conduct all their activities with due regard to the corresponding interests of all other States parties to the treaty and to enter into appropriate international consultations on activities which could cause potential harmful interference, Article VII of the Outer Space Treaty establishes the general principle that a state that launches or procures the launching of an object into outer space or from whose territory or facility an object is launched, is internationally liable for damage caused to another state party to the treaty, and to their natural or juridical persons, by such object or its component parts whether such damage is caused on the Earth, in air space, or in outer space.

The general principle enunciated in Article VII of the Outer Space Treaty has been elaborated upon in the Liability Convention. The Liability Convention establishes procedures to determine liability and compensation in the event damage is caused by a space object and the parties are in dispute as to the cause or amount of damage. A space object is defined in the Liability Convention as including component parts of a space object as well as its launch vehicle and parts thereof. Most of the orbital debris in space consists of parts of launch vehicles, usually spent stages.

For the purposes of this hearing, I will only discuss those situation where a piece of orbital debris causes damage to an orbiting spacecraft or to persons or property on board such a spacecraft and where as a result of such a collision the object returns to Earth and causes damage to either aircraft in flight or to persons and property on the surface of the Earth. In the former case, liability is based on fault, while in the latter case, both States would be absolutely liable, jointly and severally, for any property damage or personal injury caused on Earth or to the aircraft in flight. In the latter case, the two States involved in the collision causing damage to the third state on Earth each would be liable to the other for their share of the damage in accordance with the extent to which they were at fault and if the extent of the fault of each of the States could not be established, the burden of compensation would be apportioned equally between them. So if a piece of orbital

debris is identified as having come from a space object of the United States and that piece of orbital debris impacts on a spacecraft of the Soviet Union causing that spacecraft to reenter the Earth and causes damage to persons and property in the United Kingdom, the U.S. would be liable to the Soviet Union, assuming the U.S. was solely at fault, for the loss of the Soviet spacecraft and would be also liable to the United Kingdom for damage caused in United Kingdom. I should note at this point that not all launching States are parties to the Outer Space Treaty and/or the Liability Convention. For example, the Peoples Republic of China has neither signed nor ratified either the Outer Space Treaty or the Liability Convention.

Now let me take a few minutes to address some of the issues and problems I see facing those seeking solutions to reduce or eliminate the hazard of orbital debris in low Earth orbit. First, in what forum should consultations take place if the U.S. now believe that orbital debris in low Earth orbit is a serious problem that must be addressed. The most logical place for the problems and issues associated with orbital debris to be discussed and hopefully resolved would be in the United Nations Committee on the Peaceful Uses of Outer Space. The potential damage and injury that could result from a collision in space between two space objects not only involves the two States involved in such a collision but also as demonstrated above could affect non-launching States on Earth. The Committee on the Peaceful Uses of Outer Space has representatives from both launching States and non-launching States. The Committee has two Subcommittees, a Scientific and Technical Subcommittee and a Legal Subcommittee. The Scientific and Technical Subcommittee can address such issues as how to identify the state to which the piece of orbital debris belonged. Much of the orbital debris consists of very small pieces and unless the small piece, through metallurgical or chemical tests, can be found and identified it may be impossible to determine the state that should be held liable under the Liability Convention. Large pieces can possibly be identified by NORAD. In addition, the Scientific and Technical Subcommittee has or can obtain the technical expertise and the capability to identify potential solutions for substantially reducing or eliminating orbital debris. In the absence of any solutions or the inability to reach agreement among the launching States, then States can look at ways in which they can protect against damage to their spacecraft or space station caused by orbital debris. The Scientific and Technical Subcommittee can also examine the economics or the cost involved in implementing solutions that would reduce or eliminate orbital debris as well as look at alternative solutions and costs of providing protection against

damage due to orbital debris by designing spacecraft, space stations, space shuttles so as to withstand the impact of orbital debris. It may be very expensive to make changes to existing launch vehicles so as to reduce or eliminate orbital debris. Therefore it may be very difficult to reach a consensus because of the economic cost involved in solving the problem of orbital debris. However, even if this were to be the case, it may be possible to come up with recommendations that could be applicable to new launch vehicles being developed by launching States. Any agreement reached by the Scientific and Technical Subcommittee can then be reduced to writing and put into Treaty form by the Legal Subcommittee.

As opposed to utilizing the Committee on the Peaceful Uses of Outer Space, it may be useful as a first step to convene a conference of those States having launch capability as well as those States providing low Earth orbiting payloads. The purpose of such a conference would be to identify the nature and the extent of the hazard posed by orbital debris and then to discuss potential technical or engineering solutions to the problem. I am not technically competent to even guess whether a generalized solution applicable to all launch vehicles or spacecraft can be developed or whether each country must address the problem based on their individual designs or manufacturing processes. A conference of such interested parties may be more effective and expeditious than initially utilizing the Committee on the Peaceful Uses of Outer Space as the Scientific and Technical Subcommittee only meets for two weeks out of a year while a conference of interested parties could establish working groups or committees that can meet more often during the year and call on the service of its national experts to serve on such working groups. It will serve little purpose to convene such a conference without the participation of representatives of Arianespace, the United States and the Soviet Union as they are probably the major contributors to orbital debris. If the problem is to be solved, it clearly must be solved on a multi-lateral basis for as time goes by more States will develop launch capability and will be providing spacecraft to be launched in low Earth orbit. For this reason after such a conference referral to the U.N. Committee on the Peaceful Uses of Outer Space would be the appropriate forum to codify agreements reached into a treaty document.

I hope this testimony has been useful and informative to members of the Subcommittee and again I would like to express my appreciation for being invited to testify before the Subcommittee.

S. NEIL HOSENBALL

S. Neil Hosenball joined the Washington office of Denver, Colorado's Davis, Graham & Stubbs as a partner in 1986, with significant expertise in space law and government contracts matters. Immediately prior to joining the firm, he served for a year as Director of the Center for Space Law and Policy at the University of Colorado. Mr. Hosenball served as General Counsel of the National Aeronautics and Space Administration from 1975-85, and as its Deputy General Counsel from 1967-75. Earlier, he had been Assistant General Counsel for Procurement Matters and had served for four years at the NASA Lewis Research Center as Chief Counsel. Prior to joining NASA in 1961, Mr. Hosenball was in private practice in Cleveland, Ohio.

Mr. Hosenball received a B.S. from the University of Michigan (1948) and his LL.B. degree from Harvard Law School (1951). He is a member of the Ohio, Florida and D.C. Bars, and is admitted to practice before the Federal Circuit and the United States Supreme Court.

From 1969 to 1979, Mr. Hosenball was a member of the United States Delegation to the United Nations Committee on the Peaceful Uses of Outer Space and has served as head of the U.S. Delegation at Legal Subcommittee and Committee sessions. He is a member of the Board of Governors of the American Bar Association Air and Space Law Forum, the National Council of the Federal Bar Association, the American Institute of Aeronautics and Astronautics, the American Astronautical Society, the International Astronautics Federation, and the American and International Institutes of Space Law.

He was awarded the NASA Exceptional Service Medal in 1967, the NASA Distinguished Service Medal in 1973 and 1985, the National Civil Service League Career Service Award in 1980, and the Presidential Rank of Distinguished Executive in 1983. He was a Professorial Lecturer of Air and Space Law at the George Washington Law School and the University of Colorado. In 1986, he received an award from the International Institute of Space Law of the International Astronautical Federation in recognition of his contributions to national and international space law.

Mr. NELSON. Thank you, Mr. Hosenball.

Mr. Johnson.

Mr. JOHNSON. Thank you, Mr. Chairman.

I concur with the previous witnesses in appreciating the opportunity to come and talk with you about this particular problem, one that I have been involved in for many years now.

I would like to say in the beginning of my brief comments that there is no single solution. The reason there is no single solution is, there is no single source. There are a variety of sources, ones which I've delineated and spoken to in my testimony which I've given to you and provided some pictorials, I think, to better help you understand what the sources are and where perhaps we should put the initial efforts in trying to curtail first the growth of the environment and then look farther into the future if, in fact, there is a way of cleaning it up beyond the natural processes.

I would also like to emphasize a few points that I think perhaps may have eluded some of the Members or some of the audience here, and first is that the current launch rate has not changed throughout the world in the last two decades; it has remained virtually constant at about 120 launches per year. That is not the primary source of the problem. So regulating launches into space is probably, again, not the answer.

There are two basic levels of debris. We have touched on them here already. There is a large population of very small particles, hypervelocity-particles, which have induced the effects we see on the table. Those particles, again, are not necessarily life threatening. They do not threaten the operational lifetime of the satellite. They degrade satellites normally on a very modest level. But they are very numerous.

A good example: Within the last two months, the Soviet Mir space station has suffered a substantial impact on one of its windows, one which is substantially larger than the one that the shuttle itself experienced several years ago. However, again, it was not life threatening, it does not threaten the long-term duration of the space station, but it is an operational issue that both the Soviets and ourselves and other space-faring nations will have to live with.

Of primary concern, though, is the larger debris which can cause catastrophic damage and which does not have to be very large in order to do that. We need to talk then about the sources of those debris, and of these 7,000 objects that we've talked about so often today, over half have originated from satellite fragmentations. That is, in fact, the primary source not only of the tracked population of these 7,000 but the primary source of these smaller particles which are untrackable and will remain untrackable for the foreseeable future.

The question then is, why are the satellite fragmentations occurring? Some clearly are deliberate, some have been associated with anti-satellite tests, as have been commented on, but they do not significantly—are not a significant part of the current environment, they are a very, very small part. There are other military reasons, there are other operational reasons why, through the years, particular satellites have been exploded or disposed of prior to reentry.

What is perhaps of even greater importance is, we do not know the cause of a large number of satellite fragmentations. There are two reasons for that. One is simply, there is a lack of data. They were old satellites, nonfunctional, they were rocket bodies, they simply fragmented unexpectedly, and it's very hard to do a Sherlock Holmes kind of a process and find out what caused it. We have tried in many cases. To elaborate on our statement earlier, we have not yet been able to definitely say that any one spacecraft has exploded because it has naturally run into any other object, be it natural or man-made.

What we do see, though, is a trend in low-Earth orbit, particularly over the last 12 to 18 months, of an increase in the number of sizable fragmentations, fragmentations which produce dozens or even hundreds of objects at a time, fragmentations which are occurring at those altitudes which are frequented today by manned spacecraft and which will be frequented by the great space stations of NASA, the international community, and the Soviet Union in the 1990's. Those perhaps are of greater importance, I think, to this committee.

Five of those seven events have been deliberate, have been conducted by the Soviet Union; two have been unexplained. Again, they related to Soviet objects, but there is no reason at this stage to believe that they were done intentionally. That's important, because it may be, again, a subtle indicator of what the environment is. These particular objects which have fragmented have fragmented at the higher altitudes, still low-Earth orbit but at around 1,000 kilometers or 1,500 kilometers, where the density of the satellite population, the tracked population, is already much greater. So the odds of having that kind of an event are already enhanced.

Finally, I would like to, as I have in my testimony, reiterate the comment earlier that we are approaching solar maximum. This is a tremendous opportunity for all space-faring nations and organizations to take advantage of a very significant natural occurrence.

At the end of solar max, in the early 1990's, virtually all particles, both the tracked and the untracked population, below 600 kilometers will be substantially cleansed. That, of course, is the altitude that we are looking at for flying manned spacecraft in the future, space stations. Both ours and the Soviets will be flying around 500 kilometers. The issue then is to prevent the re-accumulation of debris in this area.

Now there will always be debris decaying naturally from the higher altitudes. We can't do much about that, at least in the near term. But the flux of that debris will not present a significant hazard to manned spacecraft. The issue perhaps that is narrow enough to be attacked and perhaps narrow enough where we can find some international cooperation is to limit our initial investigations or our initial guidelines or operational procedures to this lower altitude environment which first directly affects manned spacecraft.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Johnson follows:]

NICHOLAS L. JOHNSON
Advisory Scientist

TELEDYNE BROWN ENGINEERING
1250 Academy Park Loop
Suite 240
Colorado Springs, CO 80910

719-574-7270

Mr. Nicholas L. Johnson is an internationally recognized authority on the Soviet space program and space debris. He is the author of four books on the Soviet space program and is the sole author of the widely acclaimed annual report on Soviet space activities, The Soviet Year in Space. Three of his books are part of the American Astronautical Society's Science and Technology Series and include the authoritative two-volume set of the history of the Soviet deep-space and manned space flight programs (1957-1980) and a comprehensive analysis of all Soviet space programs during the period 1980-1985. Mr. Johnson is also the author of Soviet Military Strategy in Space, published by Jane's Publishing Company, and is the primary contributor to Jane's Spaceflight Directory for Soviet space systems.

Mr. Johnson has served as Guest Lecturer at the U.S. Air Force Academy, the Air Force Institute of Technology, and the Naval Post-Graduate School. As well as speaking at technical and popular forums in the U.S., Canada, and overseas, he is the author of numerous articles appearing in scientific and military journals and books, including Space Policy, Advances in Space Research, Journal of Spacecraft and Rockets, and Soviet Armed Forces Review Annual. Mr. Johnson is also the co-author of the book Artificial Space Debris.

Mr. Johnson is presently Advisory Scientist for Teledyne Brown Engineering, supporting a wide variety of Government space-related projects since 1979. He was previously Manager, Space Systems Analysis at TBE's Colorado Springs office, where he directed all Space Defense, Space Surveillance, and Space Debris analytical activities. In addition to supervising the development and exercise of a large, end-to-end computer simulation of anti-satellite weapon systems and communications networks for several Government agencies, Mr. Johnson was in charge of realtime space event evaluations, space surveillance software, space object identification, satellite breakup analyses, and space environment issues. He designed an automatic foreign launch processor and unknown satellite identification software for operational use in the NORAD Space Surveillance Center. He remains a principal author of the NASA-sponsored technical report History of On-Orbit Satellite Fragmentations, which is updated periodically to reflect all satellite breakups. Under his direction all NORAD satellite catalogs were revised and enhanced, and a new database management system for all historical foreign space launches was created.

Mr. Johnson has served tours of duty with both the U.S. Air Force and the U.S. Navy. In the latter capacity he was Director, Heat Transfer and Fluid Flow Division, at the U.S. Naval Nuclear Power School. Mr. Johnson is a Fellow of the British Interplanetary Society and a member of the American Institute of Aeronautics and Astronautics.

THE SPACE DEBRIS HAZARD IN LOW EARTH ORBIT

Testimony of

NICHOLAS L. JOHNSON

Advisory Scientist for

TELEDYNE BROWN ENGINEERING

Before the U.S. House of Representatives Subcommittee

on Space Science and Applications of the

Committee on Science, Space, and Technology

13 JULY 1988

WASHINGTON, DC

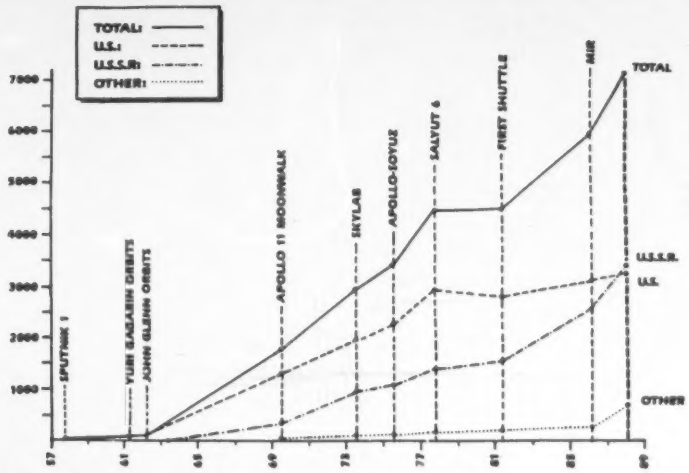
Despite the apparent immensity of space, the near-Earth environment is quite finite. This is especially true for that volume of space within 2000 km of the Earth's surface which is home to the vast majority of all known artificial satellites. This region is of vital interest to both civilian and national security missions: manned spaceflights, navigation, meteorology, search and rescue, remote sensing, surveillance, and science. Yet today too few take heed of the fragility of this global natural resource. Like the Earth's oceans, the seas of space are not immune to the indiscriminate activities of man.

The state of space debris today should not be viewed apocalyptically. By all accounts, space debris do not pose a serious hazard to operations in space today. However, projected environments for missions envisioned in the 1990's could alter this situation. Already these projections are adversely affecting the design of future spacecraft, e.g., the NASA International Space Station. Likewise, operations of the Hubble Space Telescope will surely be affected by artificial space debris, perhaps significantly.

The growth of the near-Earth satellite population has continued virtually unabated during the nearly 31 years of the space age. Today more than 7000 objects with a diameter of 10 cm or more are known to be in orbit about out planet. At collision velocities of 8-10 km/s, these satellites carry explosive-like energy. Of even greater importance to satellite operators are the estimated tens of thousands of smaller man-made debris which can still cause catastrophic damage to unsuspecting satellites but which elude all efforts of detection with present-day terrestrial sensors.

The figure below depicts the increase in the official satellite catalog maintained by U.S. Space Command (formerly prepared by NORAD). Contrary to popular belief, this steady rise in the satellite population is not due to a growth in general space activities. Since 1965 the world-wide space launch rate has remained essentially unchanged at approximately 120 missions per year. Only near the end of the 1970's was the satellite growth rate sharply curtailed. However, we can take no credit for this partial respite in the population explosion in near-Earth orbits which was caused by accelerated orbital decay of low altitude satellites under the influence of high solar activity.

SPACE OBJECTS CATALOGED (IN ORBIT)



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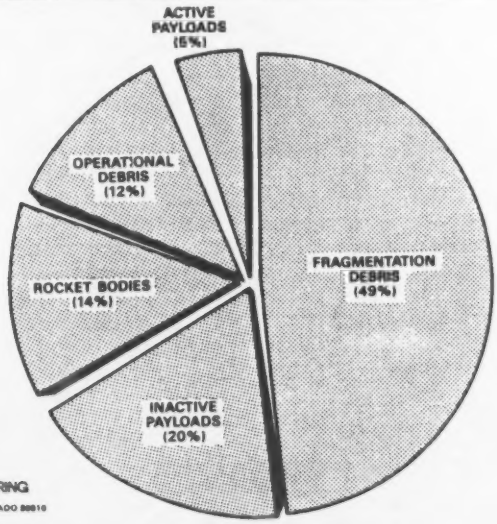
CATALOGED EARTH SATELLITE POPULATION, 1 APRIL 1988



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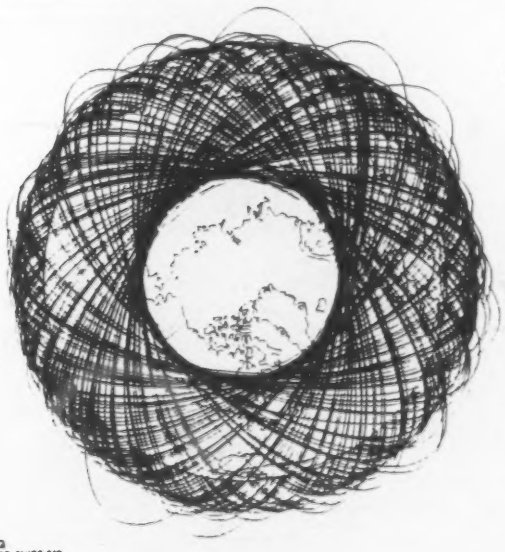
Only 5% of the identified objects in Earth orbit represent operational spacecraft. The remainder constitute varying types of space junk which can be categorized under four general headings. Spent rocket bodies and inactive (dead) payloads together make-up about one third of the Earth's satellite population. Operational debris, which account for another 12% of the total population, are objects intentionally discarded during satellite delivery or satellite operations and include lens caps, separation and packing devices, spin-up mechanisms, empty propellant tanks, or any object thrown away or dropped during manned activities outside a spacecraft. However, for more than a decade about one-half of all objects in orbit about the Earth have originated during satellite fragmentations, both deliberate and accidental.

Since the first recognized satellite fragmentation in June, 1961, nearly 100 satellites - payloads, rocket bodies and even "debris" - have experienced on-orbit breakups. Debris thus generated eventually spreads out, encircling most of the entire globe and posing risks to a large number of other satellites. The figure below indicates the orbital paths of the debris remaining today from that first satellite fragmentation 27 years ago.

1961-OMICRON DEBRIS ORBITS 1 APRIL 1988



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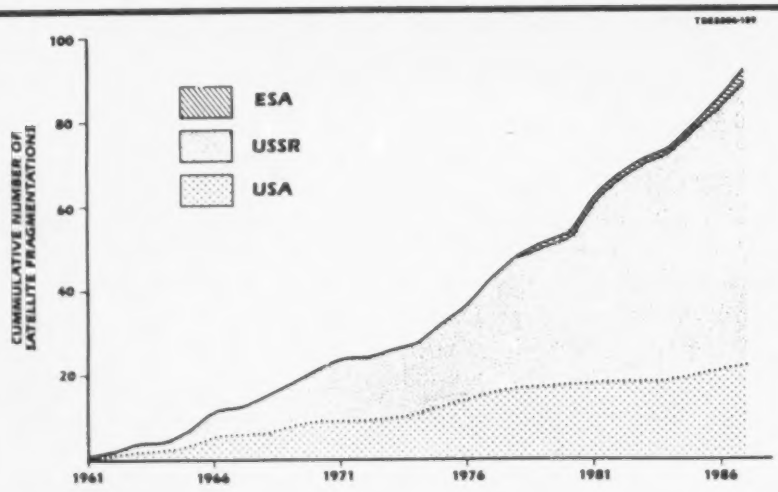
Of particular concern is the recent increasing rate of major satellite fragmentations in low Earth orbit. The unexplained breakup of an Ariane rocket body in November, 1986, instantly increased the total Earth satellite population by about 7% with the creation of 500 large pieces of debris. Many thousands more fragments too small to be detected by radars and optical sensors now pose collision hazards to more than 100 operational payloads.

Within the past 12 months seven high intensity fragmentations - all originating from Soviet satellites - have been recorded. At least five of these were deliberately initiated and occurred at altitudes frequented by manned spacecraft. The other two fragmentations took place at high altitudes where the known satellite population is more dense and may have been the result of collisions with space debris. Although more than 1000 fragments from just these seven events were detected by the U.S. Space Surveillance Network, less than 20% have been cataloged. Consequently, the magnitude of the space debris problem is often underestimated by researchers relying solely on official satellite catalog documentation.

HISTORY OF SATELLITE FRAGMENTATIONS



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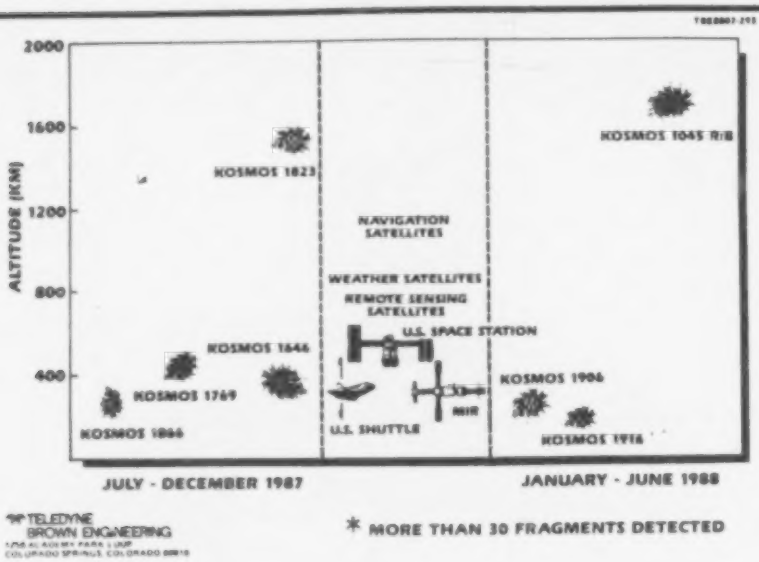
RECENT LEO SATELLITE FRAGMENTATIONS*



TELEDYNE BROWN ENGINEERING

* MORE THAN 30 FRAGMENTS DETECTED

In addition, a growing number of anomalous events - one or a few objects inexplicably separating from old satellites - are being detected. These happenings may provide valuable insight into the true nature of the Earth's satellite population, but they are rarely analyzed by the scientific community.

The reluctance to recognize the space debris issue is paradoxically greatest among many satellite owners and operators. Admittedly, in 30 years of operational experience no satellite is known to have been seriously disabled by artificial space debris (although several satellites have ceased functioning or broken-up for unknown causes). However, this position is at best short-sighted. Many colleagues here today will agree that space debris currently pose only a slight hazard to space operations, but unless some space activity philosophies are fundamentally modified, a serious space debris problem will develop. The debate is simply about how soon this situation will occur. Regrettably, the definition of the space environment is sufficiently poor today to prevent an accurate prediction of when space debris will pose more severe hazards.

Underlying the debate is the possibility that by the time space debris begins to affect space operations detrimentally, our ability to institute a cost-effective remedy may be limited. Carried to its logical conclusion, space debris in low Earth orbits could grow to the point where they are self-regenerative, i.e., the rate of debris generation by satellite-satellite collisions will exceed the rate of debris removal by natural sinks. If we wait until serious side effects of space debris manifest themselves, we may be too late.

The first requirement in reducing the potential hazards of space debris - and one which has virtually no economic impact - is to curb the creation of unnecessary orbital debris. Intentional satellite fragmentations should be sharply curtailed and conducted, when necessary, under strict guidelines to ensure rapid decay of all debris. The Delta-180 test in September, 1986, is an excellent example of responsible planning of a debris-generating experiment in space to meet scientific or national security objectives. By careful orbit selection about one-half of all debris was destroyed during reentry within one hour of the experiment with most of the remaining debris decaying within a few months.

Operational launch debris should also be minimized or eliminated whenever possible. Most operational debris is generated needlessly and without awareness of its potential adverse effects. Minor redesigns of rocket bodies to accelerate decay and the adoption of new launch procedures to take advantage of natural decay forces should be encouraged. The more rapid removal of such objects from low Earth orbit will eliminate them as targets for space collisions and hence as inadvertent sources of secondary debris.

The retrieval of large satellites, while commendable, will have little consequence on the growth of the debris population. The energies and expense required for such missions can normally be put to better use by investigating techniques and technologies to remove the greater number of small satellites.

Within the next few years we and other space-faring nations and organizations will be presented with the opportunity to affect noticeably the safety of future space travelers. The onset of solar maximum early in the next decade will substantially cleanse the environment below an altitude of 600

km. During the mid-1990's two great space stations - one built by NASA and its international partners and one constructed by the Soviet Union - will be deployed at altitudes near 500 km. Actions taken by the U.S. space industry and Government and by other foreign space users can ensure that we do not unnecessarily repopulate the region of near-Earth space below 800 km. Similar regulations and guidelines could later be applied to even higher altitudes.

It has been said that the Earth is the cradle of man and that man must leave his cradle to grow. The pollution of space, then, threatens this evolution. Even today we rely heavily on satellites for many of our routine activities, from weather satellite photographs on the nightly news broadcasts to telephone and television relays to a host of other services. If the space debris population remains unchecked, all space activities - manned and unmanned - will suffer. In the words of the American Institute of Aeronautics and Astronautics, "corrective action must begin now to forestall the development of a serious problem in the future."

Mr. NELSON. Any questions from the committee?

What do you think about some international regulatory body looking at this problem for the future?

Mr. HOSENBALL. I don't know whether you need a regulatory body. There are several that are available right now who play a role as far as satellites are concerned. You could—it seems to me that if the parties agree that certain standards are to be met, certain things are going to be done, and that could be done through a multilateral agreement of some sort, it seems easy enough that you'd be able to tell whether they're living up to that agreement, and if in fact, there is debris created as a result of a satellite explosion or spent stage, you could then call for an examination of what they are doing.

Rather than setting up another international body, I think it can probably be done through consultation and agreement that the parties would live up to as a treaty obligation.

Mr. NELSON. Do you agree with that, Mr. Johnson?

Mr. JOHNSON. Yes, I do.

Mr. NELSON. Do both of you basically agree with the former panel on the question of zero growth policy?

Mr. HOSENBALL. It's a complicated question. I think the suggestion made by Mr. Johnson is a good one. We ought to move forward very quickly to see whether we can't solve the problem in this period. I think there will be difficulties. I don't know whether—all launch vehicles, I assume, are not the same; all satellites are not the same. Are you going to get into technology transfer problems in these negotiations? It's not going to be an easy subject to resolve, but at least we ought to start now and address the problem, be aware of the problem and move forward.

Mr. JOHNSON. Mr. Chairman, without having any details of zero growth, because it's obviously a very simple title for a concept which is certainly more complex, that option would need to recognize the fact that there are different altitudes with different hazards. Debris is not uniformly distributed around the Earth, at least in altitude, so that generating more debris, for instance, at 2,000 kilometers is not necessarily a hazard even to the satellites at 2,000 kilometers and certainly does not affect those satellites working in the manned-oriented regimes.

So zero growth would need, at a minimum, to take into account the altitude factor and what the true hazard is for different regimes.

Mr. NELSON. Any further questions?

You talked about the decay because of the sun cycles that are going to occur in the early nineties. We might point out that, you know, now is the time for us to do something about this and take advantage of that phenomenon because thereafter, in the late nineties, the phenomenon is exactly the opposite.

Mr. JOHNSON. Yes. So it's much more a question of curtailing future growth, because we will have this cleansing problem.

Mr. NELSON. Okay. It's been a good hearing. We appreciate it. We're getting into this subject.

The meeting is adjourned.

[Whereupon, at 12:30 p.m., the subcommittee was adjourned.]

APPENDIX I

Responses to Questions by
Subcommittee on Space Science and Applications
Committee on Science, Space, and Technology
U.S. House of Representatives
(letter dated 15 July 1988 by Hon. Bill Nelson)

1. QUESTION: Are there currently any proposals for retrieval of debris that are economically or technologically feasible? Are there likely to be any soon?

ANSWER: To date proposals for the retrieval of space debris have fallen into two categories: conventional and innovative. The conventional methods utilize classical orbital rendezvous techniques similar to those employed by STS in the recovery of the Westar 6 and Palapa B2 satellites in 1984. Such missions are severely limited in the amount of debris which can be collected and without exception are uneconomical in light of their influence on the total Earth satellite population. Some innovative concepts, e.g. use of electric or magnetic fields to slow down charged debris, hold promise as potential long-term techniques for reducing the small Earth satellite population, but both the economics and the technologies involved have not been fully defined. No near-term artificial removal mechanism of significance to the Earth satellite population is anticipated.

2. QUESTION: What percent of fragmentation events in orbit are of unknown origin? Is it possible that a number of these are caused by debris collisions?

ANSWER: The attached illustration indicates that of the nearly 100 recognized satellite fragmentations during the first 30 years of the space age, 45% are of unknown origin. In large measure this is due to the fact that 75% of these "unknown" fragmentations involved Soviet satellites (payloads and rocket bodies), and the U.S.S.R. has never commented on the breakups. However, none of these Soviet fragmentations are seriously suspected of having been deliberately induced as in the cases of Soviet ASAT tests and malfunctioning recoverable spacecraft. In addition, several "unknown" fragmentations occurred in the 1960's when active and passive monitoring methods were less capable. Although natural collisions with meteroids or artificial space debris may have been the causative agent in several of the fragmentations, only the event involving the Soviet Kosmos 1275 in 1981 is thought by many as a likely collision candidate. Since 4 October 1987, two more unexplained fragmentations may have been caused by collisions, but insufficient analysis has yet been performed to assign a likelihood.

CAUSES OF SATELLITE FRAGMENTATIONS

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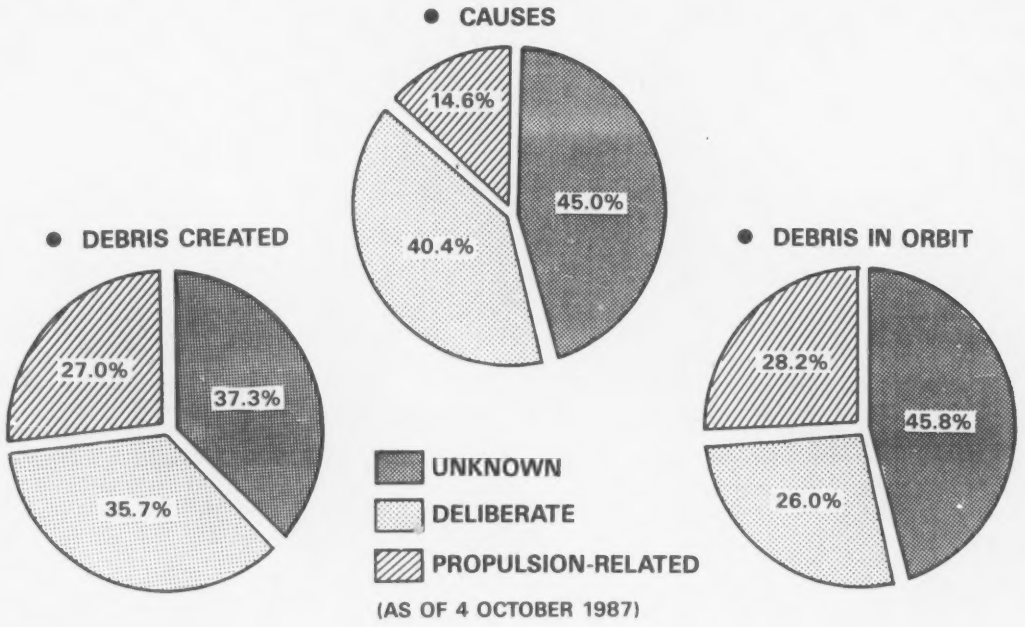

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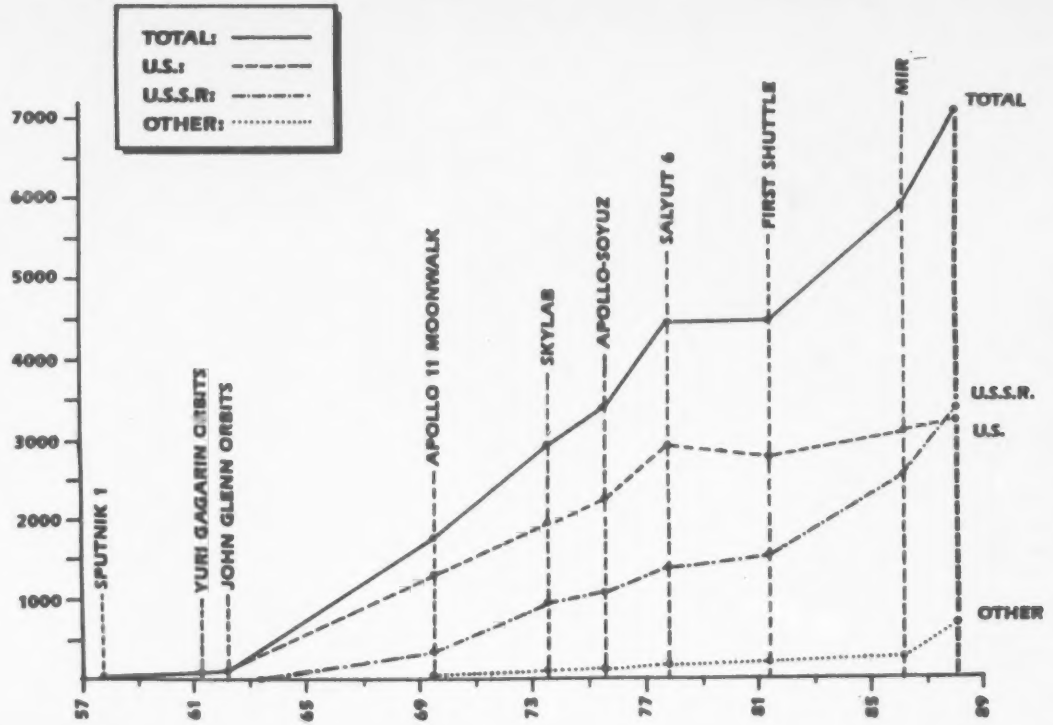
3. QUESTION: What is the estimated change in flux of tracked and untracked objects during the next solar cycle below 500 km? Below 1000 km? How will this effect Shuttle, Station, and Telescope debris collision probabilities?

ANSWER: With great uncertainties in the intensity and duration of the next solar maximum, a confident answer to this question is not possible. However, some quantifications are possible using the cataloged satellite population of 1 July 1988. On that date 800 satellites possessed perigees of 500 km or less. Of these, 30% were in highly elliptical orbits which are governed more by solar-lunar gravitational perturbations than by atmospheric drag. The magnitude of this group is likely to remain relatively unchanged with new operational debris and rocket bodies replacing similar reentering objects. However, the very short periods each day which these satellites spend below 500 km (typically 10-15 minutes per day) result in only a very slight hazard to satellites like STS, Space Station, and Space Telescope. From the remaining 70% (about 560) of the satellites with perigees now below 500 km, more than one-half can be expected to reenter naturally by 1992-1993. In the absence of future satellite fragmentations, this population will not be significantly replaced by future launch operations. Satellites decaying from higher altitudes will be another source of replenshment for the regime below 500 km, but during solar maximum those higher altitude satellites with the greatest ballistic coefficients will be preferentially removed, resulting in a decreased "rain-down" effect following solar maximum. Hence, the total spatial density below 500 km will decrease significantly after solar maximum if satellite fragmentations are sharply curtailed and no major change in international space operations at these altitudes occurs. Normal logistical support of manned space stations need not adversely affect this assessment.

Another 800 satellites are now found with perigees between 500 and 600 km. These are the objects which would most directly affect operations of a space station at 500 km. Only 3.3% of these satellites fall into the highly elliptical category. Hence, natural atmospheric decay accelerated by solar maximum could dramatically reduce the spatial density of objects in this altitude regime. An additional 3000 satellites now have perigees between 600 and 1000 km. Only a small percentage of these satellites will be significantly affected by solar maximum. However, the assumed, much greater population of uncataloged satellites (below 10 cm in diameter) at these altitudes will be markedly influenced by solar maximum. Hence, the true hazard to STS, Space Station, and Space Telescope will again be reduced.

4. QUESTION: Would it be possible to significantly reduce our contribution to the debris environment without decreasing the worldwide launch rate?

SPACE OBJECTS CATALOGED (IN ORBIT)



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COLORADO SPRINGS, COLORADO 80910

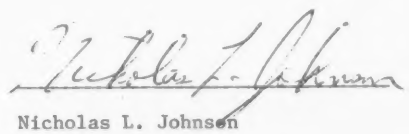
ANSWER: Yes, the primary factors in the growth of the Earth satellite population are satellite fragmentations and operational debris. Both can be largely eliminated without affecting the international launch rate.

5. QUESTION: Can you give us a summary of known and hypothesized debris collision events?

ANSWER: All low altitude Earth satellites are routinely hit by natural and artificial (man-made) debris. However, these particles are extremely small and rarely have any immediate effect on the mission of the spacecraft. In many cases these strikes merely result in an erosion or pitting of the satellite exterior which is not detrimental. Several hits on U.S. and U.S.S.R. spacecraft windows or sensors have been detected, but none have cancelled a mission or posed a serious threat to crew safety. As noted in the answer to Question 2 only a handful of satellite fragmentations are currently suspected of having been caused by an accidental collision.

6. QUESTION: Can the U.S. hope to diminish growth rates of the population through stringent unilateral efforts?

ANSWER: The accompanying chart, included in my original testimony before the Subcommittee, indicates that during the past 10 years, the U.S. contribution to the known Earth satellite environment has remained essentially constant while that of the U.S.S.R. has increased dramatically. Since the beginning of this decade the U.S. total satellite population has increased by only 10% in comparison to a 215% increase by the Soviet Union. Therefore, unilateral action will not noticeably affect the current growth rates. However, the setting of a realistic national space debris policy will set a precedent that could facilitate the establishment of world-wide space debris guidelines.



Nicholas L. Johnson
Advisory Scientist
Teledyne Brown Engineering

United States Department of State

Washington, D.C. 20520

July 28, 1988

Dear Mr. Chairman:

Following the hearing held on July 13 on Orbital Debris at which Mr. Michaud testified, additional questions were submitted for the record.

Please find enclosed the responses to those questions.

Sincerely,

J. Edward Fox

J. Edward Fox
Assistant Secretary
Legislative Affairs

Enclosures:
as stated

The Honorable
Bill Nelson, Chairman,
Subcommittee on Space Science and Applications
Committee on Science, Space and Technology,
House of Representatives.

Q. If the U.S. wishes to promote its policy of minimizing debris accumulation, is it necessary that other nations be signatories to the 1967 Outer Space Treaty?

A. Because the Outer Space Treaty does generally address the question of potentially harmful interference with Outer Space activities, as well as liability for damage caused by space objects, it would be desirable to have other nations become parties to the Treaty. The Department of State is leading the interagency review of the relationship between space law and the debris issue.

Q. Does Article IX of the Outer Space Treaty require that the U.S. and the U.S.S.R. engage in international consultations if they plan to engage in activities such as ASAT tests that generate hazardous amounts of debris?

A. "Debris" is not a legal term used in the Outer Space Treaty; rather, the legal standard used in Article IX is "potentially harmful interference." If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals would cause potentially harmful interference with the activities of other States Parties in the peaceful exploration and use of outer space, then the Outer Space Treaty requires that it undertake appropriate international consultations before proceeding with such activity or experiment.

Q. When will we begin negotiations with the internationals on debris minimization?

- In what forum will this take place?

A. We can explore potential approaches to debris minimization with other governments in a useful way after we have come to some conclusions within the U.S. Government about which approaches would best serve U.S. interests. Those conclusions will be based on the work already underway in the interagency study. The modalities and venue of discussions with other governments will be determined in light of the specific objectives we may wish to pursue. It may be prudent to first share and analyze information on the nature and scope of the debris problem before discussing measures to minimize debris.

THE UNDER SECRETARY OF DEFENSE

WASHINGTON, D. C. 20301-2000

POLICY

Honorable Robert Roe, Chairman
Committee on Science, Space and Technology
2321 Rayburn House Office Building
U.S. House of Representatives
Washington, DC 20515

Attention: Subcommittee on Space Science and Applications

Dear Mr. Chairman:

In reply to the Subcommittee's additional questions on the space debris issue, I am submitting the attached responses for inclusion in the printed record.

Very respectfully,

Philip Kuhsberg
Assistant Deputy

Attachment
a/s

Question: What is the current assessment for probability of failure of an SDI satellite due to a debris collision?

Answer: A number of factors such as the size of the satellite, the altitude it was placed at, and the year it was launched, as well as, what debris growth model to use, would have to be considered before an accurate estimate could be given. In the year 2015, a satellite presenting a 40 square meter surface area, launched into low earth orbit, could expect to be struck by a 1 cm size piece of debris, once every 95 years, assuming continuation of the current 5% per year debris growth rate.

During the last two fiscal years, the SDIO through its Survivability Project has funded a $800,000 NASA study of the debris issue. It has also funded a multi-year program to develop defensive shields which have the capability to stop small pieces of debris travelling at orbital velocities. These two programs and a substantial manuever capability in each Strategic Defense System satellite should minimize the probability of failure due to collision.

Question: If DOD is allowed to resume ASAT testing, what specific procedures would it follow to limit debris? Would this involve testing at lower altitudes, (i.e. lower than the P78-1 test at 530 km.)?

Answer: The DoD currently has no scheduled ASAT testing; however, a debris assessment will be conducted prior to any further testing and specific procedures for debris limitation will be formulated at that time. Results of the interagency working group study on space debris, presently underway, will be useful for developing such procedures.

Given that low altitude testing in the Delta 180 experiment resulted in the complete cleansing of trackable debris in just over 180 days, it is a procedure likely to be used in future testing, if test requirements can be met.

Question: Of the 10% of fragments from the Delta-180 test that did not re-enter the Earth's atmosphere within 6 months, how much is still in orbit, and how long is it expected to stay there? Approximately how many small fragments are created in such an explosion (based on ground-test data)?

Answer: The vast majority of trackable debris created by the Delta 180 test had decayed from space and burned up on re-entry within 90 days. The last trackable object associated with that test decayed on 14 April 1987, approximately 7 months after the experiment.

Based on ground-test data and extrapolation, thousands of minute pieces of space debris could have been created. These pieces are too small to track and catalog. They would have been thrown into the same or similar orbits as the trackable pieces and should have decayed in the same period.

Question: How often does the Satellite Surveillance Network notify satellite operators of a need to maneuver out of a debris fragment's orbit?

Answer: The United States Space Command does notify satellite owner/operators of satellite breakups and they are capable of providing predictions of a close approach by a cataloged object if requested. However, the U.S. currently has no process by which satellites are maneuvered based on detection of space debris; to date, there has been no validated need for such a capability. In addition, it is not clear that satellite maneuver is the most cost or mission-effective remedial measure since the approach carries severe penalties on mission duration and performance, as well as being extremely expensive and complex to employ. Nevertheless, improved space surveillance capabilities would substantially enhance the U.S. ability to detect and assess debris and are likely to be considered in addressing the projected environment of debris in space.

Question: Would an ASAT test that generates a significant amount of debris require a waiver from the President's space policy?

Answer: There are no provisions in the National Space Policy that require waivers for ASAT testing. The policy does require that the design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost-effectiveness. This provision will be implemented in the planning for any future ASAT tests.

Question: What type of interagency review would be required for approval of a debris generating operation such as an ASAT test?

Answer: National Space Policy makes no provision for interagency review of debris generating operations; however, the aforementioned policy on space debris is applicable to all agencies. DoD would advise the National Security Council prior to conducting a test that was likely to generate a significant amount of space debris.

Response to Additional Questions from the Department of Transportation

#1. QUESTION:

Under what circumstances would you deny a license to a commercial launch vehicle or mission on the basis of debris considerations?

ANSWER:

The Office of Commercial Space Transportation focuses on the risk posed to other active spacecraft that may result from the proposed mission. This includes risks resulting from a planned mission and those resulting from possible mission failure. An unacceptably high level of risk would be a basis for denial of a license.

Our policy is to seek to minimize the creation of space debris existent with mission requirements and with cost effectiveness. We examine the proposed mission to determine whether there are any unique characteristics that should be considered. Regardless of whether the mission is unique or not, the final determinant is the level of risk posed commensurate with cost effectiveness. Launch license applicants must specifically address on-orbit safety issues, debris and reentry hazards in their application.

#2. QUESTION:

How would debris regulations be likely to affect the competitiveness of the commercial launch industry in the international arena?

ANSWER:

Debris regulations would likely have a significant effect on international competitiveness. Rapid growth in the commercial market and the imposition of additional restrictions or requirements on U.S. firms that other countries do not impose on their own launch providers could place these companies at a considerable competitive disadvantage. Sending satellite customers off-shore for launch by entities that are not as concerned about space debris as the U.S. is could have the unintend effect of making the problem worse.

#3. QUESTION:

If the industry develops their own guideline, would you see the need to promulgate regulations?

ANSWER:

It would depend on the guidelines developed and their effectiveness in dealing with the problem. If self-regulation proves to be ineffective, consideration of regulatory approaches appropriate, including costs and benefits associated with various options.

#4. QUESTION:

Could the development of reusable launch vehicles help to reduce our contributions to the debris population?

ANSWER:

No, the answer is no longer that simple. The vehicles of choice in the future will depend on their cost to manufacture and operate.

A growing number of nations are now viewing space as being more than just a place to do research or to build national defense systems. Because commercial power in space may determine the economic standing of individual earth nations, the drive to tap the potential uses of space has resulted in governmental and private space programs. The Europeans, Japanese, Chinese and Soviets have stepped into the ELV launch services market along with American companies trying to offer the most attractive combination of vehicle reliability and cost.

The use of reusable launch vehicles would be an important consideration if they existed and offered the least cost/best reliability option in commercial markets. It cannot be assumed that our major space competitors will drop their current vehicle lines and forego the ability to compete.

We believe that the most viable near term solution is effective regulation by DOT that creates incentives for other nations to fall in line with the performance standards that apply to U.S. commercial firms.

#5. QUESTION:

Will you solicit private sector input on your regulatory approach?

A. Will COMSTAC be asked for advice?

B. Will you solicit public input in the Federal Register?

ANSWER:

yes

A. yes
b. yes

Responses to written questions submitted by Chrm. Nelson resulting from the July 13, 1988, hearing.

QUESTION 1:

How would you expect the debris population to grow if we successfully applied the recent Presidential space policy?

ANSWER 1:

If the President's National Space Policy directive on orbital debris was applied world-wide (i.e., the implementation of orbital debris control measures by all spacefaring nations), the growth in the tracked debris population (debris 10 cm or greater in diameter) would be reduced to about one-half its current rate or less. In addition, the growth in untracked debris (debris smaller than 10 cm in diameter) would be slowed, such that the debris population in this class would decline over the next decade or two. By the third decade, however, theoretical calculations show that random collisions between tracked debris already in orbit, such as satellites and spent rocket bodies, will begin to become important sources of debris, and will, consequently, cause the untracked debris population to begin to rise again. The process by which existing debris generate new smaller, debris fragments can be mitigated by implementing the Presidential policy so as to include changing the current practice of leaving spent rocket stages in orbit. The removal of spent stages by causing them to reenter would further reduce the growth rate of the tracked debris population, and could delay by several decades the growth of smaller, untracked debris resulting from collisions between larger debris which we are currently capable of tracking.

The U.S. contribution to the debris environment peaked in 1980. Since then, the debris in orbit which is attributable to U.S. sources has declined by 15 percent. This positive trend is a result, in part, of debris control measures practiced by NASA since 1982, such as the venting of unspent propellants from Delta upper stages in order to prevent inadvertent explosions. However, the overall rate of debris growth has continued unabated. This is due to the increasing frequency of USSR explosions and satellite breakups in the earth's orbital space, which has offset the decline in orbital debris of U.S. origin.

QUESTION 2:

If we were to take no preventive measures, what would the debris population be under various growth models in 2000? In 2010? (Please indicate estimates for the tracked population, as well as the untracked population, where possible.)

ANSWER 2:

During the past two decades, debris has grown at an average rate of about 5 percent per annum. If no preventive measures were initiated, it is reasonable to expect that the debris population would continue to increase at the same rate. Assuming this to be the case, a simple extrapolation shows that the current 7000 objects

which are tracked by Space Command (i.e., debris 10 cm or greater in size) will grow to 13,000 objects in the year 2000, and to 20,000 objects in the year 2010. In addition, conservative estimates indicate that debris of the size not currently trackable (i.e., smaller than 10 cm) will increase significantly. The growth of small, untracked debris must be estimated from theoretical models, since we have no actual measured data on the growth of this class of debris. These models predict that satellite collisions will occur with increasing frequency during the next few decades. Since collisions produce many more small debris fragments than large fragments, it is reasonable to assume the growth rate for small debris would be twice that for the tracked population, or about 10 percent. This would imply that the current estimated population of 35,000 untracked 2 to 10 cm objects could possibly grow, based upon theoretical models, to 100,000 in the year 2000, and 300,000 by the year 2010.

QUESTION 3:

What specific measures are currently being undertaken to improve the 25 km uncertainty in debris orbit tracking?

ANSWER 3:

A new ground-based orbital debris radar system is planned to provide measured data on the population density of debris in the 1 to 10 cm range to altitudes of 500 km. While this radar, if developed, will yield data for debris much smaller than that we can now measure (10 cm or greater), the orbital altitude determination for these smaller particles will not be obtained to a better precision than is currently achievable. It is important to note that the radar is designed to measure in a statistical fashion the orbital debris population density at low earth orbit altitudes; it is not intended to perform as a tracking radar for the 1 to 10 cm class of debris.

Partially completed studies undertaken by the Air Force Space Command have resulted in a reasonable calculation of the actual uncertainty in the accuracy of orbital debris tracking. The specific results are classified, but the accuracies are a function of at least the following:

a. Observation data quality
b. Observation data staleness
c. Future vector propagation
   - Computer models
   - Environment models

QUESTION 3a:

How will this affect the current Shuttle policy of "no avoidance"?

ANSWER 3a:

The current Shuttle policy per the Flight Rules addresses two distinct phases of operation: the launch phase and the on-orbit phase. For the launch phase, the launch will be held to the next even minute if it is predicted that the flight plan of the Shuttle would lead it to collide with tracked debris within an eight hour

period after orbit insertion. Two analytical tools are used to make this determination: the U.S. Space Command's Computation of Miss Between Orbits (COMBO) and the Eastern Space and Missile Center's Collision Avoidance on Launch (COLA). It is not anticipated that this policy will change as a result of measures undertaken to decrease the uncertainty in orbital debris tracking. With respect to the on-orbit phase, the current rule states that no action will be taken to avoid predicted near misses between the Shuttle and known orbital debris. However, in consideration of results from U.S. Space Command studies, a proposal to revise the rule is currently under NASA Management review.

QUESTION 3b:

When and by how much is this error margin expected to be reduced?

ANSWER 3b:

There is no specific program under way to reduce this error margin. As computational techniques, improved modeling and more accurate data become available, they are introduced into the process to improve the accuracy of the collision prediction. No maneuver to avoid a collision is made unless the probability is greater than 1 in 100,000 (the level of risk taken by other NSTS elements).

QUESTION 4:

What is the projected probability, by the year 2000, that the Space Shuttle or Space Station will be close enough to an object of any size that normal operations will be disrupted (by collision avoidance, loss of pressurization, loss of life, etc.)?

ANSWER 4:

The orbital debris threat, while not yet critical, requires further study to refine our understanding of the debris environment as well as to develop measures to manage the impact of orbital debris upon space operations. Orbital debris could interrupt the operations of the Shuttle by necessitating a launch delay, an on-orbit collision avoidance maneuver, or an actual collision. Short (one minute) launch delays, as elaborated upon in response to 3a, are expected routinely according to current estimates. It is also currently estimated, assuming the spacing contained in the recently proposed flight rule and using the year 2000 tracked debris model, that a collision avoidance maneuver for the Shuttle will be required on the order of once per five flights. The frequency of maneuvers is primarily a function of the designated safety zone surrounding the Shuttle which serves to safeguard against uncertainty in the tracking of debris. This estimate does not account for debris too small to be routinely tracked (less than 10 cm in diameter) since avoidance maneuvers cannot be executed for debris not included in the tracked debris catalogue. Finally, the probabilities for actual collision of debris with the Shuttle sufficient to disrupt normal operations (debris 0.5 cm or greater in diameter) have been calculated to be approximately one impact per 71 years of continuous on-orbit operation for the 1988 debris environment and one impact per 26 years of continuous on-orbit operation for the year 2000 debris density.

Space Station operations also could be disrupted by the impact of debris or by collision avoidance maneuvers. Recent studies completed at the NASA Johnson Space Center have calculated that there will be about one collision between debris 1 cm and larger and the Station, assuming the debris accumulates at the current rate, by the year 2000. At this time, however, Space Station maneuver requirements remain indeterminate. Additional accuracy studies and evaluation of candidate maneuver strategies are required to determine the number and type of avoidance maneuvers that might be required. As a result, it is not currently possible to provide a comprehensive estimate of the impact of orbtial debris upon Space Station operations.

QUESTION 5:

How much (in terms of both financial cost and energy) would an average collision avoidance maneuver for the Space Station cost? What size particles will the Station have to avoid under current design requirements?

ANSWER 5:

Since the full range of requirements for collision avoidance maneuvers require further study and are currently indeterminate, it is not possible, at this time, to estimate the cost of an average collision avoidance maneuver. In the case of particles greater than 10 cm, which can be tracked with existing assets, an avoidance maneuver would be executed. The orbits of these particles are known, and maneuvers can therefore be planned long before the execution of such a maneuver is required. A collision avoidance maneuver could be performed quite efficiently (on the order of one to five feet per second) and could either be a full reboost or only that required to sufficiently distance the Station from the tracked debris. The net propulsive cost could be zero if the avoidance maneuvers are incorporated into the reboost strategy. There may be disruptions of experiment operations, but this could be minimized through appropriate coordination and scheduling. Given the likely advance warning (several days) of the need to perform avoidance maneuvers, such coordination would be feasible.

At present Space Station shielding for critical components is being designed to provide protection against objects 1 cm in diameter or smaller. In addition, the concept of multiple bumper shields is being examined as a means of protecting the Space Station, against particles smaller than 10 cm. Thus, the Space Station, if such a concept is implemented, would only undertake avoidance maneuvers for particles 10 cm or larger.

QUESTION 6:

What is the total cost of the debris radar program mentioned in your testimony?

ANSWER 6:

The cost for construction and initial testing of the orbital debris radar is estimated to be $24.1 million over a period of five years (1988-1992). This sum includes operation for several months at a

continental U.S. site to collect sufficient data to determine the Space Station shielding requirements. For long-term monitoring of orbital debris, it is planned to move the radar to a near-equatorial site and to operate the radar over a period of years. Until this site has been determined, the installation and operation costs cannot be defined. Sites under consideration include Ascension Island, Guam, Kwajalein Atoll, and Diego Garcia.

QUESTION 7:

How does the Space Shuttle program get information from COLA (Collision Avoidance on Launch) and COMBO (Computation of Miss Between Orbits) for Shuttle flights?

ANSWER 7:

COLA information is provided by the Range Safety Officer at Eastern Space and Missile Center (ESMC) to the Flight Dynamics Officer (FDO) in the Mission Control Center. COMBO information is provided to the FDO by the Space Defense Operations Center (SPADOC) in the Cheyenne Mountain Air Force Station (CMAFS). The precise location and velocity of the Shuttle is provided by the FDO. Similiar data or vectors for other orbiting elements are provided by the Space Surveillance Center in CMAFS.

QUESTION 7a:

How does the Shuttle program use this information?

ANSWER 7a:

The Shuttle program uses this information per the Flight Rules as described in response to 3a. To date, COMBO projections resulted only in advisories to the Flight Team. In the future, assuming the proposed rule, which allows for on-orbit maneuvers to avoid debris, is approved, COMBO collision projections may result in collision avoidance maneuvers.

QUESTION 7b:

Has a Shuttle flight ever been rescheduled or in any way altered on the basis of information received from COMBO or COLA?

ANSWER 7b:

To date no Shuttle flight has been altered in any way due to COMBO information.

However, on several flights, there have been small (one minute) preplanned cutouts during the launch window as a result of COLA information. To the best of our knowledge, this has only affected the planned liftoff time on one flight. The launch was slipped to the next minute; there was no operational impact. COMBO or COLA projections are unlikely to cause serious schedule or flight plan concerns, unless they necessitate launch delays occurs on flights with extremely short launch windows.

QUESTION 7c:

How would information from COMBO or COLA conceivably affect a Shuttle mission?

ANSWER 7c:

As described earlier in response to 3a, a Shuttle launch might be delayed for short (one minute) periods in the launch window. If the proposed Flight Rule concerning the on-orbit maneuvering of the Shuttle to avoid debris is approved, then, on the basis of COMBO or COLA information, orbital debris avoidance maneuvers may be executed.

APPENDIX II

SPACE WORLD, July 1988

Space Debris

Orbital clutter may reach the point where spaceflight becomes a "hit-or-miss" proposition

by Nicholas L. Johnson and Darren S. McKnight

Contrary to popular belief, during the last 20 years the worldwide annual space launch rate has remained virtually unchanged, yet during this same time interval the known Earth satellite population has increased sixfold. Clearly, this trend cannot continue without adversely affecting the legitimate interests in the exploration and exploitation of space.

The sheer immensity of space is the largest obstacle to the recognition of the space debris issue. For centuries the terrestrial seas, similarly thought to be nearly infinite in expanse, were the object of man's abuse and indiscriminate activity. The dumping of refuse and toxic materials into the seas was not only accepted, but often encouraged; better to pollute the seas than man's own habitat. The relief of man's burden was immediate and the consequences of his actions hidden—for a while at least. Because of the vastness of the oceans, few vessels ever encountered the effects of dumping, let alone were affected by it.

But the seas are finite after all, and eventually the signs of disease began to appear. Marine life began to disappear, beneficial coral reefs began to die, sightings of oil slicks and surface garbage became more frequent and finally, birds and even people who fed from the sea began to die. Not until people were directly threatened did the seafaring nations of the world come together to devise new regulations concerning their treatment of the seas.

So it has been with space. Spacefaring nations have yet to be touched by the space debris problem except in rare incidents of minimal importance. The replacement of a Shuttle window is not the thing about which crusades are made. However, the danger presented by the pollution of the sea of space is no less threatening to the future of mankind than is the pollution of the terrestrial seas. It has been said that the Earth is the cradle of man and that man must leave his cradle to grow. The pollution of space, then, threatens this evolution.

The state of space debris today should not be viewed apocalyptically. By all accounts space debris today does not pose a significant long-term hazard to operations in space. As water on a stove will continue to boil after the heat has been removed, the problem of space debris cannot be solved overnight. More importantly, if we wait until serious side effects of space debris manifest themselves, we may be too late . . .

The origins of artificial space debris are as varied as the satellites from which they emanate: namely, operational activities, satellite deterioration and satellite fragmentations. Clearly the single largest source of man-made space debris has been the fragmentation of over 80 satellites since 1961. In the intervening quarter century, satellite fragmentations has accounted for over one-third of all satellites cataloged and now constitute almost one-half of the known Earth satellite population . . .

In 1981 NASA implemented a 10-year space debris assessment plan. Its goal is to lay a foundation for eventual U.S. and international agreements on the space debris issue. To this end the program plan is divided into three major areas: debris environment assessment, debris hazard assessment and space object management studies.

Before an estimate of the potential hazards of space debris can be made, the extent of the space debris environment must be better defined. NASA has adopted a three-pronged approach to tackling this task. First, ground experiments, primarily radar and optical tracking experiments and fragmentation tests, will be conducted with emphasis on understanding the nature of existing small orbital debris and debris mass and velocity distributions, respectively. Second, *in situ* experiments will be conducted. These experiments may call for dedicated sensors (radar, optical, infrared or lidar) or they may merely take advantage of other planned flight activities, e.g., examining Shuttle surfaces and material brought back from Earth orbit. Finally, NASA envisions integrating this data into a three-dimensional, time dependent mathematical model which translates launch traffic models and the above noted data into particle flux as a function of impacting size and velocity on any particular spacecraft, i.e., as a function of orbital altitude and inclination . . .

The sheer immensity of space is the largest obstacle to the recognition of the space debris issue.

The final element of the forward-looking NASA program centers on the issue of space object management. To date this potentially effective technique has primarily been applied to the geostationary orbit. Space object management includes not only the control of the space environment, but also an assessment of the effectiveness of adopted control measures . . .

The easiest course of action—the path of least political and economic resistance—is simply to ignore the issue of space debris and to continue operational practices well-established during 30 years of space activity. While this philosophy may prove workable through the near term (perhaps to the end of this century), there is little doubt that such a policy would not be successful in the long term. However, minor alterations in space activities could be implemented with only small efforts which would increase

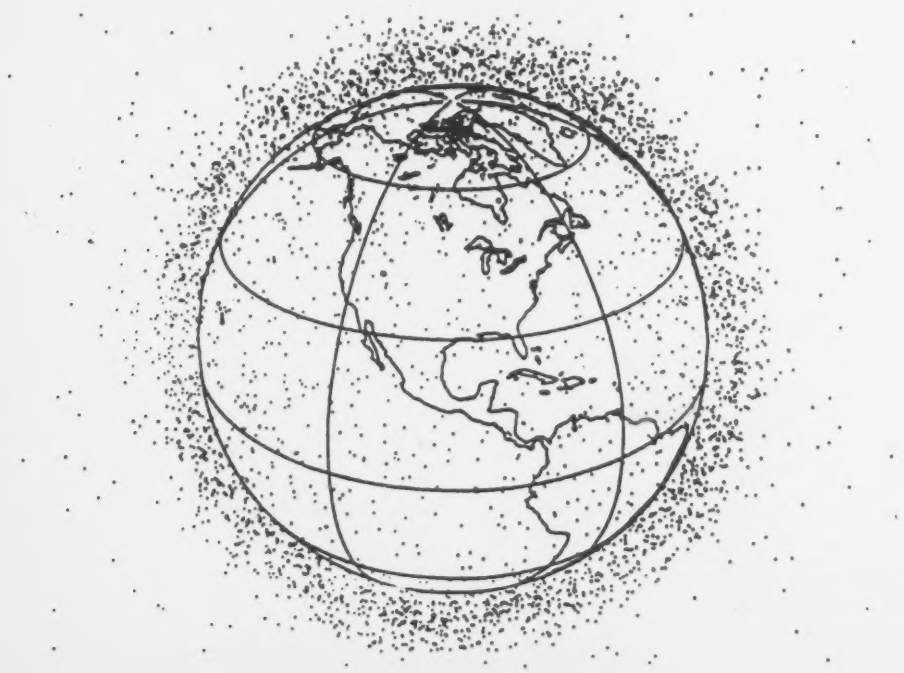
the probability of mission success during this period of increasing space debris.

Wherever possible, the mission designer could select orbital parameters which would mitigate the probability of collision with space debris. Although mission requirements and orbit types are often intimately related, some missions can accommodate a surprisingly wide range of altitudes or inclinations. Low altitude navigation satellites operated by both the United States and the USSR currently orbit the Earth at altitudes of 1,000-1,100 km. Such satellites could be moved into the less densely populated altitudes of 1,200-1,300 km without significantly affecting spacecraft design or mission performance. Likewise, a number of low altitude communications, intelligence and geodetic satellite constellations could be modified to take advantage of regions of space less susceptible to space debris encounters. More difficult to modify are the orbits of photographic reconnaissance satellites, which must fly at very low altitudes, and Sun-synchronous satellites (meteorological and remote sensing) whose orbital inclinations are dictated by their altitudes.

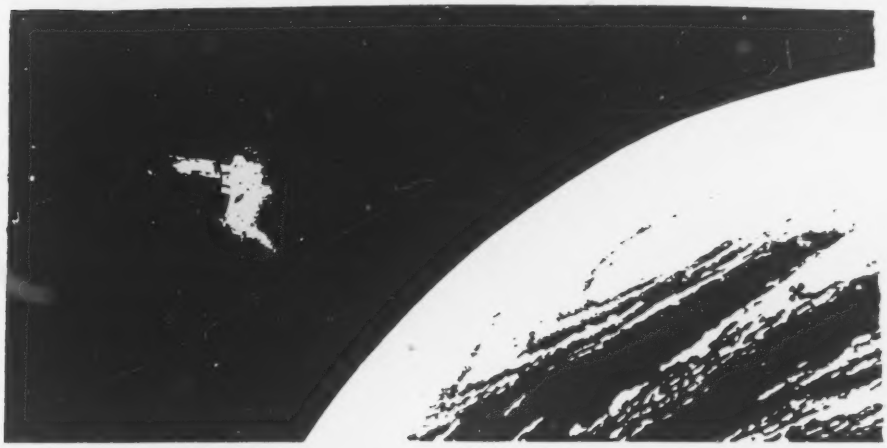
Another countermeasure to the debris hazard would be the redesign of spacecraft to tolerate impacts by larger pieces of debris. Since there are fewer larger particles, the probability of mission failure due to space debris could be lowered. Present-day satellites already incorporate shielding requirements into spacecraft design; thus only more stringent requirements would be necessary . . .

Of course, certain parts of the spacecraft such as solar panels and antennas cannot be shielded effectively. In these cases, redundancy is a viable option. For example, designing solar panels to be 10 percent to 20 percent larger than needed for power generation will compensate for solar cells destroyed by hypervelocity impacts with space debris. Auxiliary antennas could be provided to ensure mission continuance in the event one is struck by space debris. These added costs will be far less than any active measures taken to combat space debris.

Another relatively inexpensive means of reducing the probability of collision is to perform collision avoidance maneuvers . . . This technique has already been implemented in the geostationary orbit and is available as required for manned spacecraft. Most spacecraft have inherent collision avoidance capabilities by virtue of their attitude control or main propulsion systems. Even gravity gradient stabilized satellites might be successfully maneuvered along the radius vector without adversely affecting their delicate passive attitude control systems. Perhaps not surprisingly, collision avoidance maneuvers are being seriously considered for use by structures as



A NASA "snapshot" of cataloged debris as of May 1987 shows about 7,000 objects, 10 cm or larger in size in circular orbits averaging 2,000 km above the Earth's surface. A computerized, moving image of this drawing makes the debris appear like a swarm of angry bees.



Soviet antisatellite tests have significantly added to the orbital debris now circling our planet, debris that may grow to a craft and personnel-endangering level if unchecked. (Painting: William K. Hartmann)

large as NASA's Space Station when the vehicles are threatened by significantly massive pieces of orbiting debris . . .

A more responsible action, and one which is still economically palatable, is to overlay a debris acceptance program with a vigorous debris control program. Nature remains remarkably resilient to man's activities. If debris generation can be controlled, the environment at lower altitudes will in time cleanse itself . . .

Awareness of debris generation mechanisms, as discovered with the Delta second stages, can itself promote good debris control policies. Alternatives to aluminum impregnation in solid rocket propellants and even the matter of using paint less vulnerable to atomic oxygen would also go a long way toward curbing the debris environment. Better design of rocket body and payload separation mechanisms could also reduce the amount of debris now routinely being created.

A more subtle way of controlling the environment is through the refurbishment of existing spacecraft. Instead of replacing failing satellites with more satellites, the simple act of refueling or fixing satellites on-orbit could lower the annual launch rate and mitigate the growth of space debris . . .

In general, the on-orbit cleanup of space debris is not a viable option. Each of the 8,000-plus pieces of space junk now known to be in orbit about the Earth resides in a unique orbit, and considerable energy is usually required to transfer from one orbit to another. Even objects in the same orbital altitude and inclination will likely reside in different orbital planes. Translating from one orbital plane to another is an energy intensive maneuver which is rarely economically attractive.

Despite this discouraging situation, concepts for the removal of large debris (non-operational payloads and spent rocket bodies) have been offered in recent years. The bulk of the concepts envision use of the Shuttle as the primary means of transport. Two designs, one, a graduated approach to debris retrieval developed as a service extension of the Shuttle program and the other, a reusable debris hauler which uses the Shuttle only for transportation to and from its working environment, are [under review] . . .

Space debris has not yet reached a level which normally manifests itself in visible ways nor endangers routine space operations.

An even broader question is the magnitude of the benefit gained by removing large derelict space objects from low Earth orbit. Certainly, the removal of a single rocket body will reduce the chances of collision now and in the future. However, this solitary removal is statistically insignificant. To measurably lower the probabilities of collisions with space debris, a much larger number of satellites must be removed.

If an objective is to cleanse a specific region of space, a less demanding task may be effective. Assume that a large permanent space station is to be deployed at an altitude of 500 km. From this altitude most satellites will decay within 4 to 10 years, depending strongly upon solar activity. Prior to the establishment of the Space Station, if large objects

Dealing with Debris

One indicator of the seriousness of the space debris issue can be found in the Presidential Directive on National Space Policy, released earlier this year: " . . . all space sectors will seek to minimize the creation of space debris . . . Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness."

A few months ago, a White House intergovernmental space debris working group was established. Among its duties, the group is charged with recommending options to reduce space clutter, as well as how to approach other countries to secure their cooperation in what must be a global effort. One thorny issue, however, is how not to severely crimp the burgeoning U.S. commercial launch business with overly restrictive space debris regulations. Such rules could put American rocket companies at a disadvantage if not also adhered to by foreign competitors.

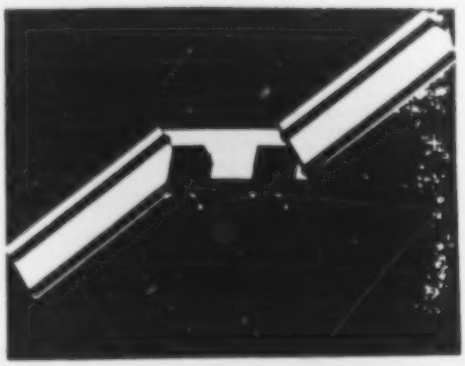
Other space debris policymakers see more trouble too. "Basically, our view is that studies show the problem is going to get worse and worse and worse," says Michael Michaud of the Science and Technology Affairs Division at the State Department.

Michaud is quick to note that the United States does not stand alone in contributing to the space debris problem—the Soviets launch many more satellites than the United States—and contends that America can't solve the problem or even mitigate it alone. "We think it's time for us to develop an international approach to the problem," says Michaud, adding, "We are particularly concerned about the Space Station, which is a major international science and technology project. It will be flying in an orbit where there is a fair amount of debris, and the consequences of debris hitting that Station with people on board could be serious."

Indeed, the Space Station as well as other large space facilities like the Hubble Space Telescope could be severely clipped by a piece of man-made orbital flotsam. Debris larger than one-third of an inch constitutes a "serious hazard," explains William Djinis of NASA's space debris steering group. "We need data. Without it, everything is just speculation."

To get that data, NASA engineers are pushing for construction of a new radar system to obtain statistical information on debris patterns up to 310 miles above Earth. The radar would ideally be located near the Equator and would be capable of identifying bits of debris as small as one-third of an inch in size, possibly even smaller. "A lot of people say, 'That's so small. Why worry about it,'" explains Djinis, "but they don't recognize when these pieces are going Mach 25, it packs a lot of energy." One calculation suggests a one-third of an inch piece of aluminum smacking into another object results in a release of energy equal to that of an exploding standard military hand grenade.

According to Robert Culp, associate director of the Colorado Center for Astrophysics Research, an estimated 70,000 pieces of debris between one-third of an inch and four inches in length are orbiting the planet. Clearly indicating the potential for danger, a paint flack that collided with *Challenger* in 1983—possible from a Delta rocket—chipped the outer layer of a triple-paned windshield, costing $50,000 to replace.



Artist's concept of a QuickSat orbital debris scanning spacecraft. The satellite would scan space with stereo telescopes for Earth circling debris down to 1 mm (1/3-inch) size pieces.

Culp and a team of graduate students are now developing computer models to track debris clouds from satellite breakups in an attempt to predict the spread and orbit patterns of space junk over time. The worst case of fragmentation in space history occurred in November 1986. A French Ariane booster exploded after delivering a payload into orbit. "That explosion resulted in over 500 trackable pieces of debris and an estimated 5,000 pieces of debris capable of destroying a spacecraft," says Culp.

One novel idea advocated by Jet Propulsion Laboratory engineers is a QuickSat debris mission. The concept would make use of a satellite carrying stereo telescopes to scan space and monitor Earth-orbiting debris. The low-cost satellite would be boosted into orbit by a refurbished Atlas-E vehicle made available courtesy of the Air Force. Simple in design, the spacecraft could be available for launch in late 1989.

So round and round they go. Where and in whose spacecraft or spacesuit they stop is anybody's guess. One can only hope that action taken to curtail the problem won't be outpaced by a catastrophe.—*Leonard David* ★

only in the 500 km altitude regime are removed, then the major future threat to the Space Station will come from higher altitude satellites decaying to 500 km. Thus a more realizable goal might be the removal each year only of large objects decaying down to 500 km. Satellites in highly elliptical and geosynchronous transfer orbits could be excluded from the set of target satellites not only because their removal is considerably more difficult, but also because the time spent in the 500 km region is so short the probability of collision with the Space Station is quite small. An offsetting factor is the possible longer orbital lifetime of the highly elliptical satellite which may result in a larger probability of collision integrated over time.

To this point only the removal of large satellites has been addressed. While these satellites will certainly cause greater damage upon collision and are themselves sources of secondary debris by collisions with even smaller satellites, their relatively few numbers make them statistically less of a threat to functioning satellites. Of primary concern are those satellites between 1 mm and 10 cm in diameter which now populate near Earth space in vast numbers. A single piece of debris only a few centimeters in diameter impacting a spacecraft at hypervelocities will carry the destructive force of a hand grenade.

Several concepts have been offered as a means of eliminating significant quantities of small debris. Don Kessler has calculated that a system—of any type—which merely retards a piece of debris whenever it passes within a radius of a few tens of kilometers of a platform will eventually make a significant contribution to cleaning up the space environment. This retarding force, which will accelerate the natural decay process, might be effected in a variety of ways. Because most debris develops a charge in space, a magnetic field could be useful in slowing down the debris. Large collecting areas of special fine-mesh nets or foam material could be deployed. Unlike the analogous flypaper, capture is not mandatory; only the slowing down of the debris is necessary. Care, of course, must be taken with the design of the system so that the impact of the debris with the device does not generate more particles than are eliminated . . .

[A] countermeasure to the debris hazard would be the redesign of spacecraft to tolerate impacts by larger pieces of debris.

The central space debris issue today is a simple one: recognition of the problem. Space debris has not yet reached a level which normally manifests itself in visible ways nor endangers routine space operations. However, continuance of the current unrestrained growth of the space debris population will ensure that space debris will someday pose significant hazards to both man and machine. Because of our imperfect knowledge of the space debris environment, simulations cannot predict with any confidence when this problem will become severe. But like a chain reaction, once natural collisions begin, the environment will start to deteriorate at an accelerated rate. At that time intervention by man may be too little, too late.

The first requirement in reducing the potential hazards of space debris—and one which has virtually no economic impact—is to curb the unnecessary creation of orbital debris. Intentional satellite fragmentations must be stopped immediately or, at the very least, carefully designed to ensure rapid decay of all debris. Operational launch debris should also be curtailed and eliminated whenever possible. Most operational debris is generated needlessly and without awareness of its potential adverse effects. The redesign of rocket bodies to de-orbit themselves or the adoption of new launch procedures to take advantage of natural decay forces should be encouraged.

The Long Duration Exposure Facility (LDEF), deployed in April 1984 and originally scheduled for Shuttle retrieval in September 1988, will provide much information about the orbital debris it was exposed to during its years in space.

The retrieval of large satellites, while commendable, will have little consequence on the growth of the debris population. The energies and expense required for such missions can normally be put to better use by investigating techniques and technologies to remove the greater number of small satellites. An exception to this rule is the removal of radioactive satellites from Earth orbit because of the special dangers they pose.

An international effort should be initiated to better define the near Earth environment. Debris measurements can be made by a host of terrestrial sensors and can be an integral part of satellites deployed in different regions in space. If warranted, dedicated space-based debris monitoring platforms could be designed and operated by such august bodies as the United Nations, the International Astronautical Federation or the Committee on Space Research of the International Council of Scientific Unions. The data collected from these investigations should then be made available to the world scientific community for the purpose of determining the extent of the space debris problem and of finding efficient, cost effective ways of improving the space environment. ★

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